NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

NATIONWIDE MOBILE COMMUNICATION SYSTEMS

by

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Chapter V - Appendix A

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V. OVERVIEW OF SYSTEM ECONOMICS

A. INTRODUCTION

Previous chapters discussed nationwide mobile communication system technologies and modeled user costs and benefits. This chapter provides a brief overview of mobile communication system economics, the projected U.S. market for nationwide mobile communications, and the potential revenues. The basic cost structure of satellite and meteor-burst systems are also modeled. A combination of all these factors will ultimately govern which systems will be commercially successful.

B. COMMUNICATION SYSTEM ECONOMICS

Basic communication system economics are reviewed below for background information.

1. Economies of Scale

Figure 68 shows how system costs, communication volume, and user charges for equipment and service are interrelated.

Because of improvements in technology, communication system costs and user terminal costs (A) per unit of capacity tend to decline over time. However, inflation tends to drive the price of an identical product upward over time. Since the cost reductions associated with electronics and computer technology are generally far greater than the inflation rate,

Economies of Scale Model

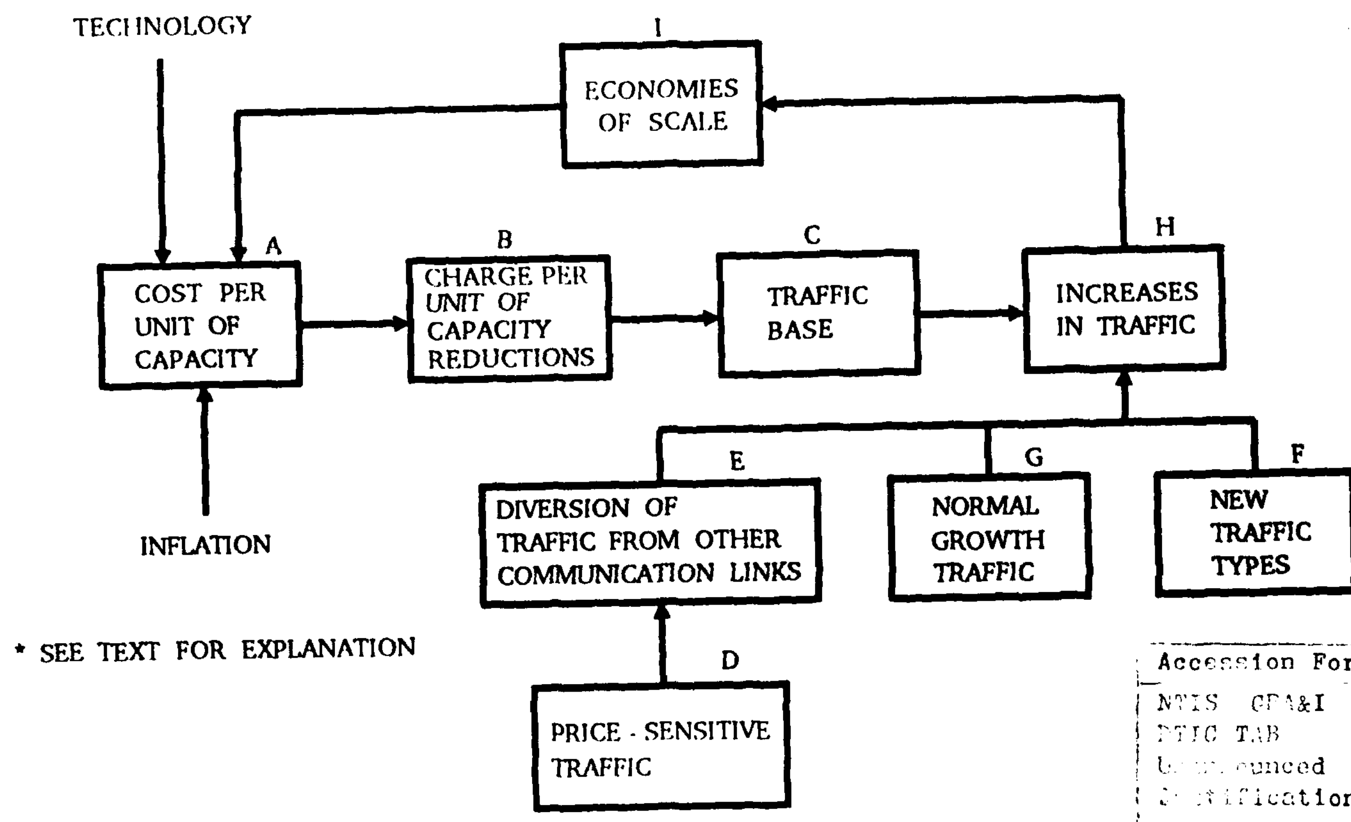

Figure 68. Economies of Scale Model

the cost of equipment tends to fall as production volume increases and time advances. This permits a reduction in the communication charges necessary to recover the costs of a system, and the price of user terminal equipment falls (B), which makes the service more attractive. This increases the traffic base (C) and the amount of price-sensitive traffic (D), which causes a diversion (E) from other alternatives. The lower prices (B) also stimulate the growth of traffic (G) and entirely new types of traffic (F). The total communications traffic carried by the system thus increases (H). These factors combine to create economies of scale (I). This process feeds back to generate more orders for system and user equipment and further reduces communication charges (A and B) [Ref. 52:pp. 83-84]. The simultaneous reduction of cellular telephone equipment and user charges is a good example of this process.

2. Market Demand and Supply

A basic understanding of demand and supply helps to explain and predict the behavior of the market in response to changing conditions. A working definition of a market is a group of firms and individuals in touch with each other in order to buy or sell some good or service [Ref. 25:p. 20]. In general, price is a major factor in the market demand for and supply of goods and services. The market demand for a good or service during any time period will usually increase as its price is lowered. Conversely, the quantity supplied to the

market during a time period will generally increase as the price is raised. This simplified relationship of quantity and price is graphed in Figure 69.

In this simple model, the sale of goods and services takes place when the sellers and buyers in the marketplace agree on a price. The total quantity bought and sold in the market will be equal to the amount the buyers are willing to purchase and the sellers are willing to furnish. This is indicated where the demand and supply lines cross.

In reality, market supply and demand curves are usually not linear. Their position and shape are determined by many factors other than price. Demand curves are influenced by the level of buyer incomes, substitutability and prices of other goods and services, and consumer tastes and preferences. Figure 70 is an example where an increase in the awareness of mobile communication system benefits shifts the demand curve to the right. In this case, purchasers require a greater quantity of mobile communications services at each price level. Both the price and quantity increase. Shifts in the location of the curve are termed a change in the quantity demanded. [Ref. 25:pp. 20-24]

Supply curves are affected by the level of technology, production economies of scale, and the basic costs of raw materials and components [Ref. 25:pp. 27-30]. The example shown in Figure 71 reflects the change in quantity supplied as the result of a change in communication technology. The

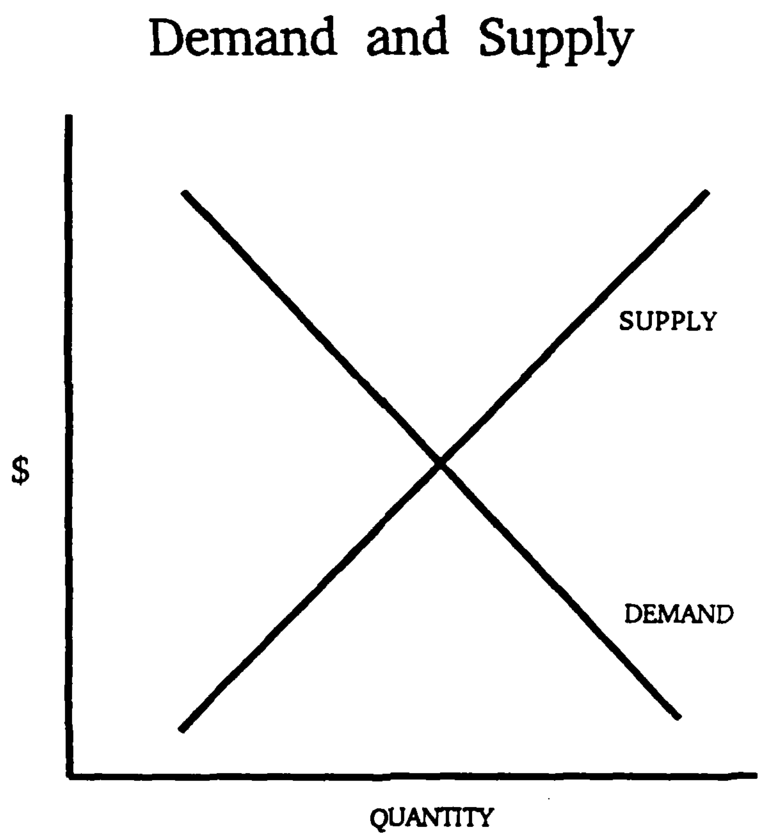

Figure 69. Demand and Supply

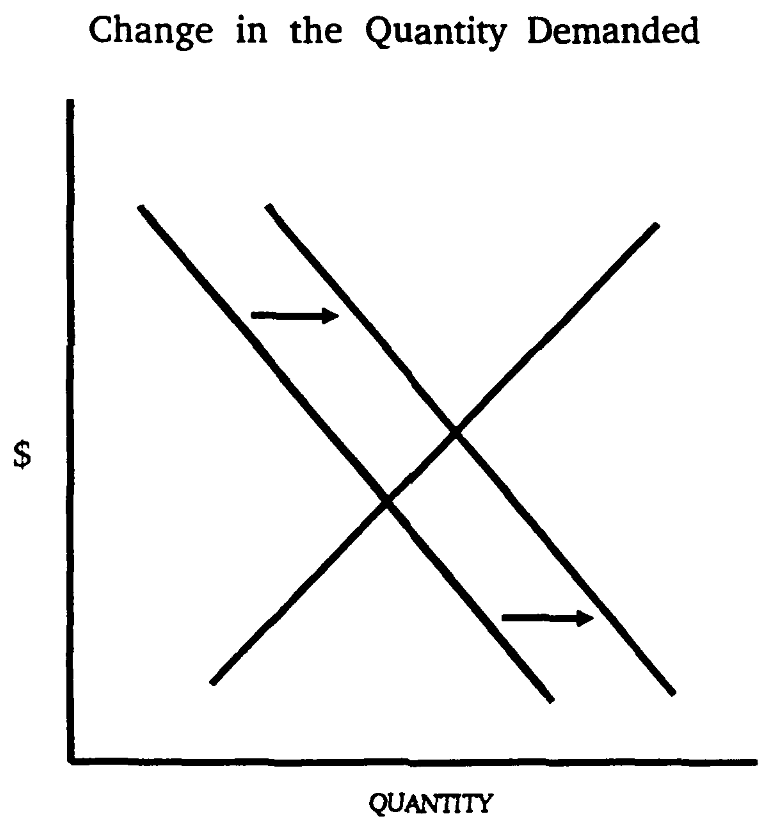

Figure 70. Change in the Quantity Demanded

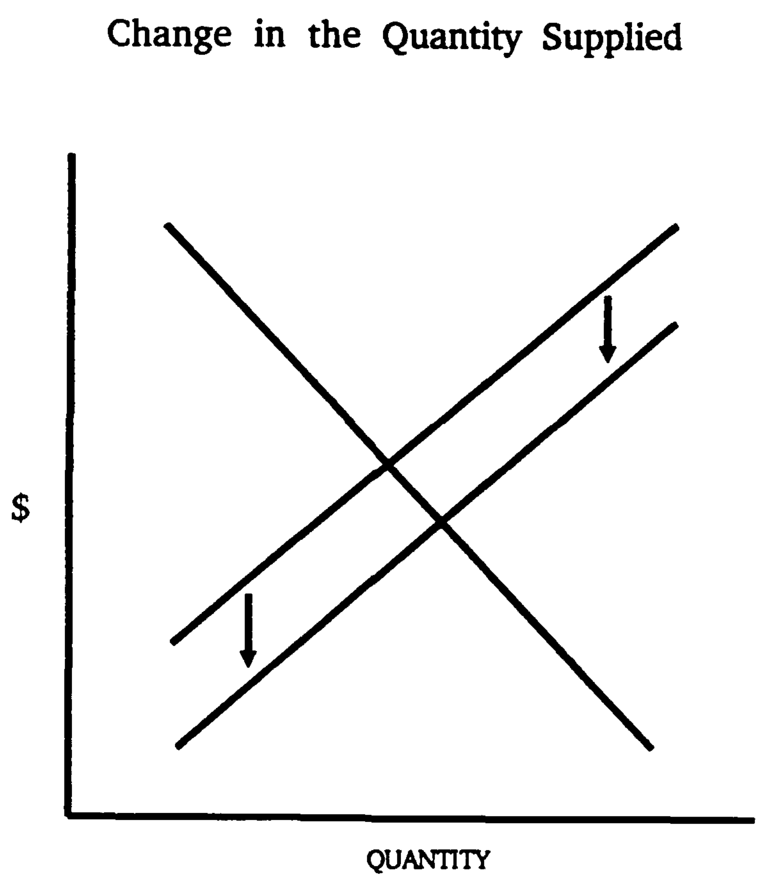

Figure 71. Change in the Quantity Supplied

supply curve has moved downward because it is now possible to provide communications services at a lower cost than before. The market price falls and the quantity demanded increases.

The timeframe under study also determines the shape and location of the curves. Longer periods of time allow buyers and sellers to be more flexible in responding to market supply and demand changes. [Ref. 25:pp. 31-37]

Both curves usually vary in their sensitivity to the relationship of the quantity demanded or supplied to price. For some goods or services, a small change in price results in a large change in the quantity demanded or supplied; for others, a large change in price results in a small change of quantity supplied or demanded. This sensitivity is termed price elasticity, and is defined as the percentage change in quantity demanded or supplied resulting from a unit percentage change in price. Elasticities are expressed in relative terms and should not be confused with the slope of the curve. For sections of the curve which are <u>elastic</u>, the percentage change in quantity demanded or supplied will be greater than the percentage change in price. For example, reducing the price by 5% generates a 10% increase in demand or sales. Conversely, for sections of the curve which are inelastic, the percentage change in quantity demanded or supplied will be less than the percentage change in price. For instance, raising the price by 7% increases the supply by only 3%. [Ref. 25:pp. 24-26, 30]

3. Potential and Target Markets

The potential market is defined as the long-run demand for a good or service, given full information about the service and the alternatives, and assuming the price to the user is zero. The target market is defined as that portion of the potential market which is willing to pay a given price for the service in the long run. The price of the service is the fully-allocated cost, which includes the amortized equipment costs and maintenance, system user charges, and long-distance connect expenses.

Figure 72 illustrates this concept. The long-run demand curve for a communication system is shown by the line DD'. The quantity Qp is the potential market for this service. When the price at which the service is offered is P, the size of the target market is measured as quantity Qt. [Ref. 14:pp. 16-17]

As discussed above, the size of the target market is not governed exclusively by price. Among other things, demand for the service is also a function of income, changes in the size and distribution of the potential user population, changes in availability and capabilities of competing technologies, and new uses which are developed.

Growth of the user population to the long-run target market is not instantaneous. As conceptually illustrated in Figure 73, both target demand and market penetration grow over time [Ref. 14:p. 18]. Experience has shown that new product

Potential and Target Market Demands

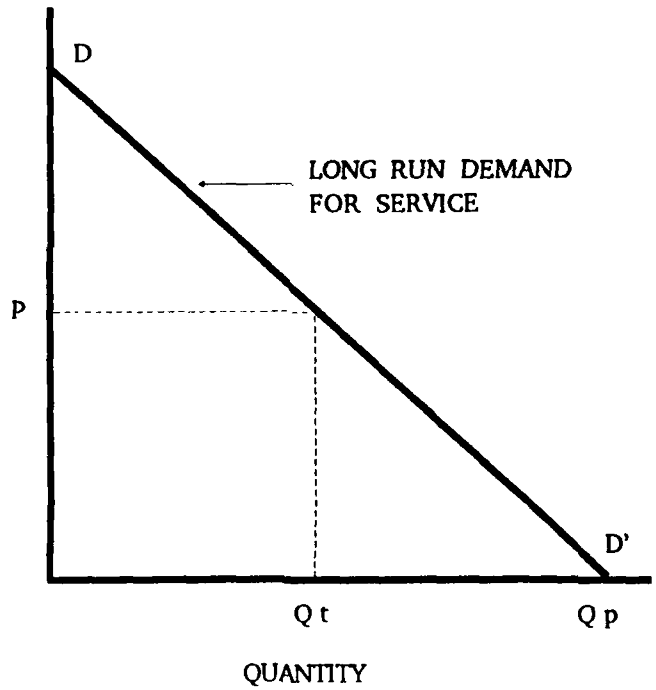

Figure 72. Potential and Target Market Demands

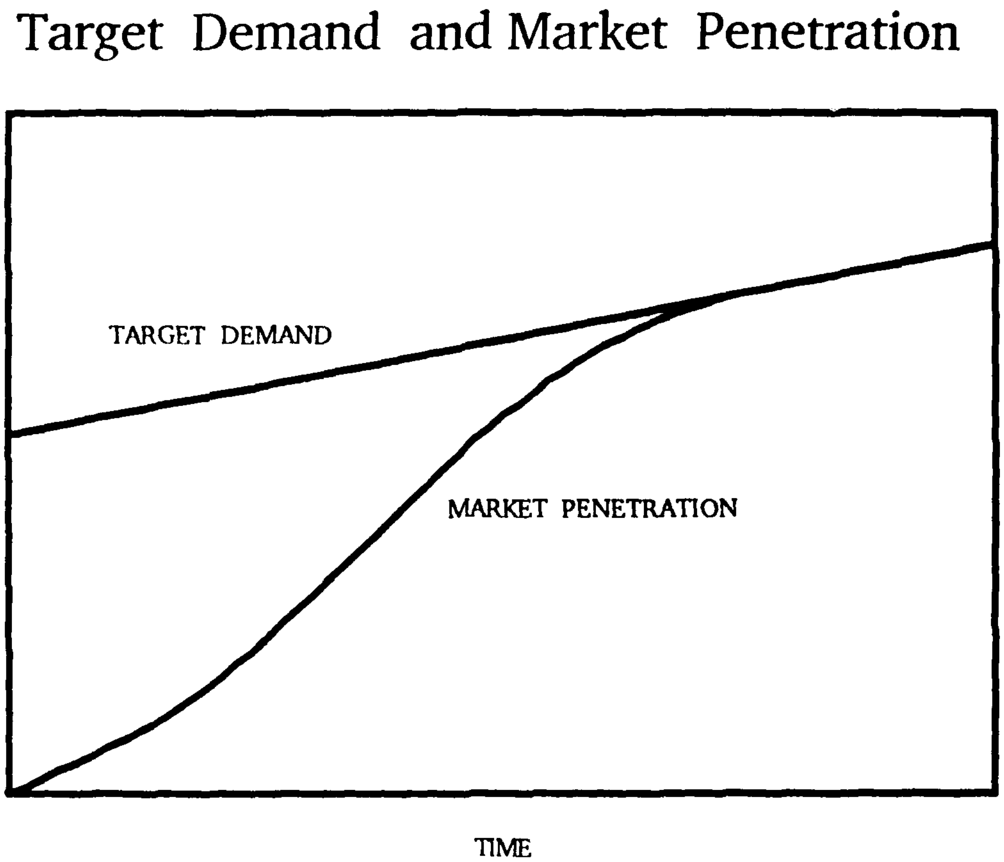

Figure 73. Target Demand and Market Penetration

and service market penetration follows an "S"-shaped curve until the target market is reached [Ref. 13:p. 13]. The level of target demand and user population at any instant depends on a number of supply and demand factors, such as:

a. System capacity available to meet demand at an acceptable grade of service.

b. Time lags associated with starting the new service, building and selling equipment, developing integrated software, etc.

c. Developing user awareness and appreciation of service capabilities.

d. Changes in prices for the service over time due to communications economy of scale.

e. Changes in the cost of user terminal equipment.

f. The rate at which users of existing communication technologies adopt nationwide communication equipment.

g. Price, service, and features of competing technologies. [Ref. 14:pp. 17-18]

4. Revenue and Profit

User tariffs can be fixed, variable, or a combination of both. In general, fixed charges do not encourage the user to conserve limited system capacity. Variable charges may not cover the cost of maintaining accounts for low volume users. A combination of fixed and variable tariffs provides a minimum level of revenue, encourages the conservation of system capacity, and allocates a greater share of the costs to those who most use the system.

In order for a communication system to be a commercial success, revenues must be large enough to recover the capital

cost of the system, fund fixed and variable operating expenses, and generate a profit. A very simple conceptual model is shown in Figure 74, where the construction of a communication system results in a series of cash outflows until the system becomes operational [Ref. 53]. Once operating, total system revenue during any time period is based on average usage times average price. Operating expenses are deducted from revenue and the remainder is used to recover the cost of the system. Eventually a point is reached where the system is paid off and a profit is earned. This is indicated where the cumulative cash flow curve crosses the breakeven line. This graphic model is an over-simplification since it assumes the communication system is completely cash financed and does not take into account financial and tax accounting practices, leases, and incremental construction.[1] However, a model similar to this can be used to rank various systems as to the number of users and level of revenues required over a period of time to recover the investment. This simple model can also be used to determine relative profitability with respect to various market sizes and shares.

5. System Capacities and Limitations

Communication systems have upper bounds on the amount of traffic they can carry, which can ultimately limit the

[1]The spreadsheet which generated this graph is capable of taking taxes and financing arrangements into account.

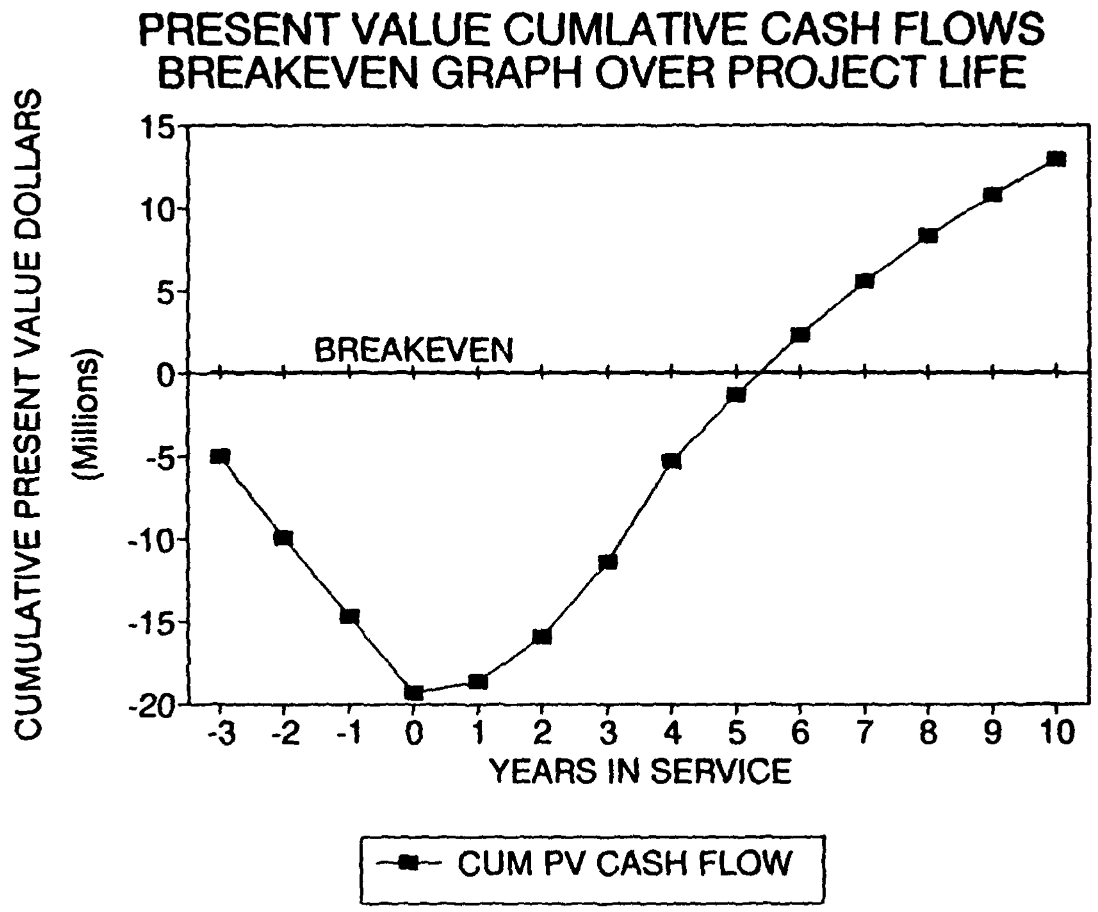

Figure 74. Present Value Cumulative Cash Flows Breakeven Graph Over Project Life

amount of revenue which is generated. In the short run, the capacity of a system depends on many variables, such as the allocated spectrum, the system technology and architecture, peak-message loading, the distribution of communications over time, average message length, type of information carried, etc. These capacity constraints are not as severe in the long run. New or enhanced systems can be developed as technology improves, and the allocation of radio frequency spectrum can possibly be expanded.

Figure 75 illustrates a short-run capacit-constrained revenue curve [Ref. 53]. When the communication system is first operating, only a small part of its capacity is used. Over time, the amount of traffic increases until the system reaches saturation. A fully-loaded system is conceptually illustrated in Figure 76 [Ref. 53]. The volume of traffic throughout the work-day consumes most of the available capacity and results in a high level of call blocking. Once this peak loading is achieved, further short-term growth in traffic is unlikely unless the distribution of calls changes. This could be accomplished by offering a reduced rate for off-peak hours. In the longer term, additional units of capacity could be added. Again, cellular telephone is a good example. Additional units of capacity (cells) are created as the communication volume goes up, and a variable rate structure is used to encourage communication during off peak hours.

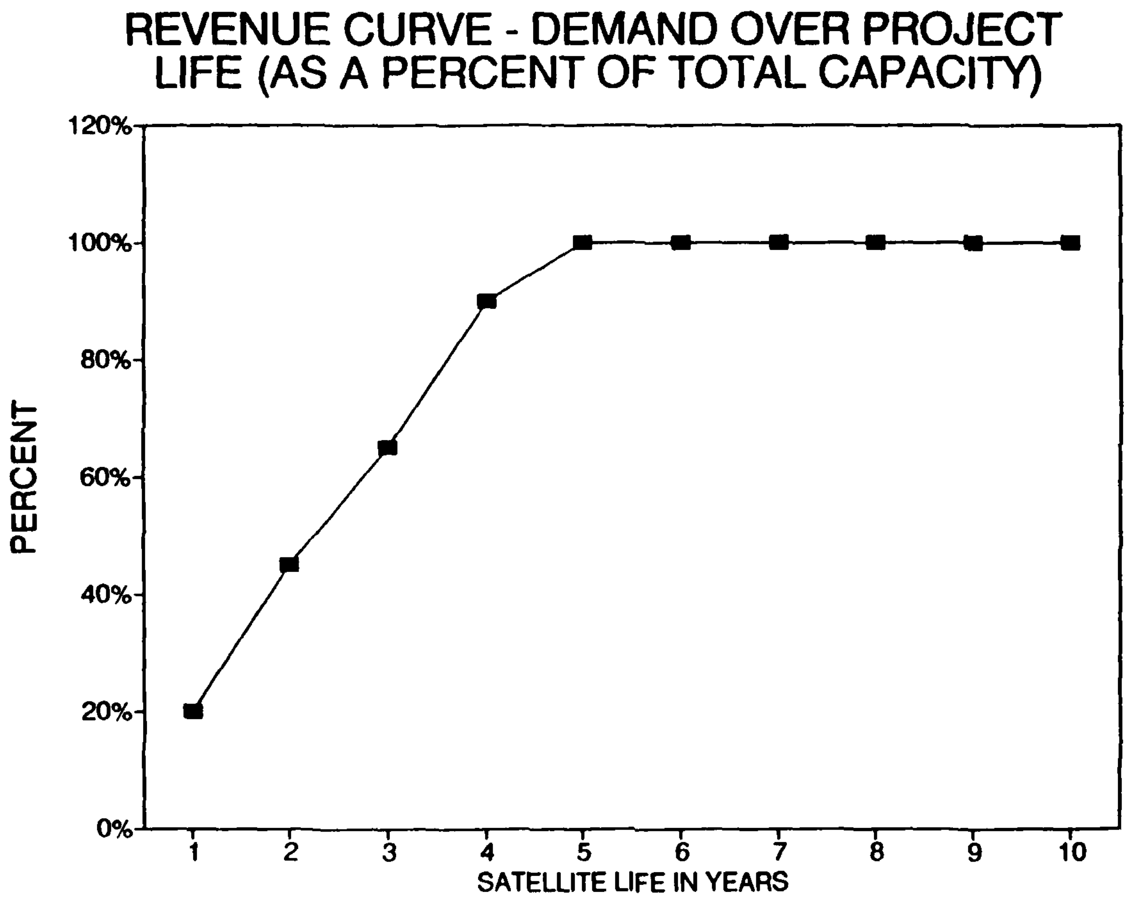

Figure 75. Revenue Curve--Demand Over Project Life (as a Percent of Total Capacity)

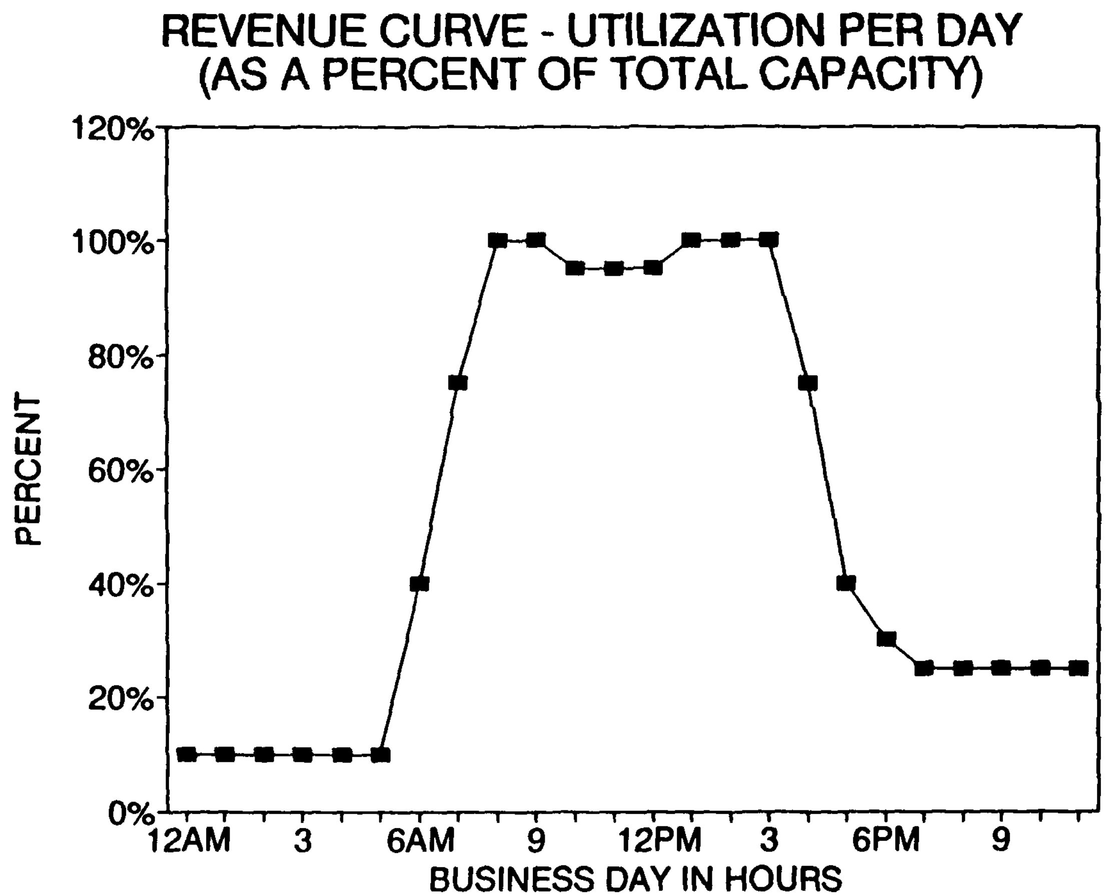

Figure 76. Revenue Curve--Utilization Per Day (as a Percent of Total Capacity)

C. PROJECTED RDSS AND MSS MARKET SIZE AND REVENUES

Numerous market studies, beginning with NASA's research in 1979, have identified large potential and target markets for nationwide voice and data communications systems [Ref. 13:pp. 6-7]. Since the details of these studies are beyond the scope of this thesis, only the major points will be discussed.

1. Research Methodology

The research methodology discussed below was not specifically described in any one of the FCC filings. However, an examination of each proposal showed similar methods to determine the potential market size, system revenues, and profitability.

The basic approach used in the studies was to identify industry and institutional groups (i.e., trucking, public safety, emergency medical services, etc.) and individual groups of users (i.e., boaters, RV owners, etc.) which could use one or more of the proposed services. Each of these groups were then sampled and questioned on the types of services they would desire (voice, data, location reporting, etc.), the highest price they were willing to pay, and the numbers of terminals they would require. The survey results were extrapolated and the market demand estimated for various price levels [Ref. 54:pp. 25-26].

Mobile terminal costs were estimated based on engineering analysis and the expected level of technology when the system becomes operational. The decline in terminal costs

over the system life was forecast based on expected production economies of scale and further improvements in technology, such as increasingly sophisticated very large scale integrated (VLSI) circuits. [Ref. 55]

The quantity of services capable of being supplied, or communications capacity, was projected based on the limitations of technology and the amount of radio-frequency spectrum which is available for use. Total cost of providing the service was estimated based on the cash flows required to recover system investment costs and operating expenses [Ref. 13:pp. 31-34]. The average service charge per user was determined by dividing the total system costs by the long-run expected average level of individual use [Ref. 13:p 33]. Long-run terminal costs were amortized and added to the average service charge to determine total average user costs [Ref. 13:pp. 26-27].

These estimates were compared to the demand data to develop a long-run target-market forecast. The short-run use and service growth was then predicted based on the supply and demand factors discussed above and expert judgment [Ref. 14: pp. 16-17].

2. Summary of the Forecast RDSS, DLMSS, and AMSC Target Market Size and Revenue

a. General

In a 1988 space industry survey conducted by the U.S Department of Commerce, forecast worldwide annual revenues

from RDSS systems were expected to reach $150 million to $200 million by 1992, and total $1 billion or more in 1995. Part of the increase in revenues is attributed to production economies of scale for RDSS terminals, with user equipment declining in price from about $4000 to less than $500. These estimates were obtained from suppliers and were not independent government forecasts [Ref. 56:p. 47].

Table 19 lists forecast terminal costs for Geostar 3.0, AMSC, Geostar DLMSS, and Omninet. The Omninet terminal production data are included for comparison[2]. The Canadian MSS supplier, Telesat Mobile Inc. (TMI), is not discussed in this chapter because cost and revenue data were unavailable.

Table 20 displays the Geostar, AMSC, and Geostar DLMSS target-market estimates for the U.S. Forecast trucking-industry use is shown in Table 21. Estimated target market revenues for each system are contained in Table 22. These data were extracted from market justification sections contained in filings made with the FCC between 1985 and 1988. The quoted market and revenue projections for any given year will be difference from what actually occurs because AMSC and Geostar have experienced some delay in meeting their forecast schedule milestones. Additionally, the Geostar DLMSS proposal was rejected by the FCC in February 1990 [Ref. 57:p. 4].

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[2]Omninet's system would provide location reporting, data, and voice services. As discussed in Chapter VI, the FCC dismissed this proposal because it closely resembled a MSS system and did not comply with Commission guidelines.

TABLE 19

FORECAST TERMINAL COSTS

Geostar 3.0:	Declining from $3000 for first generation terminals to less than $500 in mass production [Ref. 8:p. 12]
AMSC:	Between $1500 and $3500 [Ref. 13:p. 27]
Geostar DLMSS:	Under $3000 for 100K production runs in 1992, 200K in 1993, and 300K in 1994. Below $1000 in the late 1990's when availability of DLMSS equipment as an option on new cars would push annual sales volumes in excess of 500,000 units per year. [Ref. 58:p. 12]
Omninet:	Manufacturing cost of $2050 for a terminal which includes ACSB voice, 2400 bps data, and GPS when built at the rate of 25,000 per year for four years starting in 1988. This manufacturing cost could be reduced to between $835 and $1025 with investment in a fully automated production line and six custom integrated circuits. [Ref. 55]

TABLE 20

FORECAST TARGET MARKET SIZE

Forecast operation beginning in 1987
Geostar [Ref. 59:p. 176]

Year	Number of Transceivers
1987	160,000
1988	400,000
1989	720,000
1990	1,150,000
1991	1,730,000
1992	2,500,000
1993	3,460,000

Forecast operation beginning in 1992
AMSC [Ref. 13:p. 12]

	Number of Terminals		
Market	1992	1997	2004
Mobile Telephone	300,000	395,000	581,000
Mobile Radio	248,000	278,000	326,000
Aeronautical Service	17,000	20,000	25,000
Transportable Rural Service	11,000	11,000	11,000
Data-only	131,000	150,000	183,000
Totals	707,000	854,000	1,126,000

Forecast operation beginning in 1992
Geostar DLMSS [Ref. 58:pp. D-16, D-25, D-26]

Year	Organizations	Individuals*	Totals
1991	90,000	50,000	140,000
1992	145,000	170,000	315,000
1993	200,000	370,000	570,000
1994	265,000	680,000	945,000
1995	331,000	1,120,000	1,451,000
1996	397,000	1,740,000	2,137,000
1997	465,000	2,530,000	2,995,000

* Medium market penetration rate

TABLE 21

FORECAST TRUCKING INDUSTRY USE

Geostar [Ref. 8:p. 161]

Potential Market	Year After Implementation 2	4	6	8
Long haul	1.9 M	2.1 M	2.3 M	2.5 M
Local area	3.0 M	3.3 M	3.6 M	4.0 M
Subtotal	4.9 M	5.4 M	5.9 M	6.5 M
Capturable market share	5%	10%	15%	20%
Projected terminals	240 K	540 K	900 K	1.3 M

AMSC [Ref. 14:p. 43]

Potential Trucking Market	5,000,000
Total long-haul trucks	357,000
50% of the long-haul market	178,500

Note: Based on 1987 trucking industry population statistics

Geostar DLMSS [Ref. 58:p. D-11]

Year	Digital LMSS Market	DLMSS Market Share
1991	70,000	35,000
1992	140,000	70,000
1993	210,000	105,000
1994	280,000	140,000
1995	352,000	176,000
1996	424,000	212,000
1997	500,000	250,000

TABLE 22

FORECAST TOTAL SYSTEM REVENUES

Geostar [Ref. 59:p. 175]

Year	Revenues
1987	$ 24.52M
1988	74.35M
1989	144.63M
1990	242.30M
1991	373.90M
1992	498.19M
1993	629.06M
TOTAL	$ 1.987B

AMSC [Ref. 13:p. 33]

Year After Start of Service	Revenues
1	$ 12M
2	39M
3	71M
4	136M
5	207M
6-12	212M
13-15	142M
16	71M
TOTAL	$2.446B

Note: Yearly revenues beyond the fifth year of operation are limited by combined satellite capacity.

Geostar DLMSS
Organizational Customers [Ref. 58:p. D-16]

Year	Revenues
1991	$108M
1992	174M
1993	240M
1994	318M
1995	397M
1996	476M
1997	558M
TOTAL	$2.271B

Since actual satellite launches will not take place until at least 1992, the reader should convert the listed dates to years after commencing system operation.

Table 23 is an independent estimate of Class I trucking industry use of mobile data systems within the U.S. Class I trucking firms have revenues of $5 million or greater, and typically have 50 or more trucks. This estimate is based on a survey and forecast conducted by Waters Information Services in 1989. Data were obtained from about half of the trucking firms with fleets of 300 or more, and included truckload, less than truckload, and mixed service. The estimates are based on characteristics of the respondent pool in relation to the characteristics of the universe of Class I trucking fleets. [Ref. 60:p. 35]

b. The U.S. Market

The U.S. market-size estimates made in the Geostar and Geostar DLMSS proposals are two to three times that of AMSC's estimate. Part of this difference is due to additional service offerings and target-market coverage. For example, Geostar system 3.0 was forecast to capture 20% of the personal pager market, or 2.94 million units, by the eighth year of operation [Ref. 8:p. 165]. DLMSS was also forecast to capture between 28% and 40% of the total U.S. pager market [Ref. 58:p. D-45]. These two-way "personal communicators" would be used throughout the U.S. without regard to population density. In

TABLE 23

WATERS INFORMATION SERVICES

ESTIMATE OF MOBILE DATA SYSTEM USE BY CLASS I TRUCKING FIRMS WITHIN THE U.S. [Ref. 60:pp. 39, 47]

Year	Number
1989	10,000
1991	43,500
1993	72,600
1995	118,000

Note: Includes satellite and terrestrial systems.

ANNUAL VALUE OF BASIC SERVICES

Year	Revenue
1989	$ 4.2M
1991	18.3M
1993	30.5M
1995	49.6M

contrast, AMSC forecast that data-only services would account for just 150,000 terminals by 1997.

In developing its market forecast, AMSC factored out the demand for mobile communication services which could be met by terrestrial systems in the more densely-populated areas. Only businesses below a minimum geographic density were targeted as potential subscribers, with a forecast penetration rate of 5.5%. Additionally, only 2% of the estimated number of cellular telephone users were forecast to subscribe to MSS services [Ref. 14:p. 24]. As discussed below, AMSC was also much more conservative in its estimate of trucking industry adoption.

Because of spectrum limitations, AMSC calculated that its first-generation system would become saturated and revenue constrained after the fifth year of service [Ref. 13:p. 33]. AMSC stated in its 1987 filing with the FCC:

> The principal uncertainty is how rapidly the target market will be penetrated....Although the Consortium's analysis is conservative, it is clear that the aggregate market for satellite services is many times the capacity of the planned system. Therefore, changes in the many assumptions made to derive estimates of the target market would not invalidate the conclusion that a clear need exists. [Ref. 14:p. 52]

When added together, the long-run estimate of U.S. terminal population for all three systems totals about 7.1 million units. Total combined U.S. revenues over the life of all three systems is estimated to be around $6.7 billion.

c. The U.S. Trucking Industry Sub-Market

The trucking industry accounts for 1.73 million units of the 7.1 million total forecast. Geostar estimated the capturable trucking market as being 1.3 million units at the end of eight years. This was derived from a 20% share of the estimated 2.5 million long-haul trucks (for hire and private intercity) and 4.0 million local-area vehicles. This amounts to 500,000 long-haul vehicles and 800,000 pick-up and delivery vehicles. The DLMSS proposal estimated its total share of the trucking market to be 250,000 units at the end of seven years. These forecasts contrast with AMSC's more conservative estimate of only 50% of the long-haul truck population (presumably the for-hire segment), or 178,500 terminals.

AMSC's estimate tracks closest to the independent terminal population forecast shown in Table 23. However, the Waters Information Services estimate was for Class I firms only. These estimates could rise if the managers of Class I firms which deny any interest should change their minds or a large number of smaller firms and independent operators in the long-haul market adopt some form of nationwide communication. [Ref. 60:p. 35-38]

d. Market Forecast Analysis

As discussed in previous chapters, there is a considerable service overlap provided by RDSS and MSS. Each existing and proposed satellite system is capable of providing data communications and position reporting. With the exception of communication services provided by the International Maritime Satellite Organization (INMARSAT) for arriving and departing international aircraft, AMSC is the only authorized U.S. provider of mobile satellite voice services. However, the proposed Geostar DLMSS was capable of low bit-rate digital speech, and other data-only systems can incorporate speech synthesizers to translate received text messages. As a result of this competition between service and features, particularly in the area of text and data services, combining the forecast users for each system to determine the total size of the market is probably over-optimistic.

This service overlap extends to terrestrial systems as well. Aside from coverage gaps in the less-densely

populated areas, terrestrial voice and data communications systems already provide, and in some cases exceed, the capabilities of RDSS and MSS. As terrestrial systems continue to expand and are networked throughout the more-densely populated regions of the U.S., the importance of satellite coverage to some potential market segments may diminish over time. The Geostar system 3.0 and DLMSS market forecasts made between 1985 and 1988 probably did not fully take into account the expansion and nationwide networking of specialized mobile radio (SMR), mobile data systems, and pagers. Also presumably not fully factored into the forecast was the development of mobile meteor-burst systems and the substantial growth of cellular telephone, nationwide cellular networking, and rural service area (RSA) expansion.

As mentioned above, these satellite-based systems have also suffered schedule slippages for various reasons. This further compounds the loss of potential satellite service subscribers to expanding terrestrial systems.

Mr. Olaf Lundberg, the Director General of INMARSAT, stated in a November 1988 speech:

> In the wake of the extraordinary march of cellular across the map of Europe and much of the rest of the world, one may ask if there remains a market for satellite-delivered land mobile communications services and if so, where does it lie?....It is serious because no one--yet--has any accurate idea about the nature or size of the satellite market....It is serious because the correct answer to that question...will determine whether more than one land mobile satellite system can survive in any given area.

In this age of market research specialists, one would think that finding the answer should be easy enough. Throw enough market researchers at the problem and one should end up with some reasonably reliable projections. But we have ...difficulties here.

To begin with, the potential market is not a fixed target. Yesterday's axioms quickly become today's folly. Two short years ago, the common wisdom in many parts of the world held that cellular radio was only an urban phenomenon, that it would be too costly to extend service into rural areas, and that land mobile satellite terminals would sell like hotcakes to fill the vacuum.

Two years can be an eternity in this business. Already, cellular radio has penetrated 85% percent of the geographical area of Great Britain, and will soon reach similar penetrations in France and other major European countries. The remaining 15%--those areas not reached by cellular--are <u>by definition</u> areas of trivial population density.

Two years ago we were saying, even within the corridors of INMARSAT, that a sizeable mobile satellite market would be found in rural and remote areas of industrialized countries. Now, after the relentless spread of cellular, we remain less convinced....

I have a difficulty with some of the published land mobile satellite market projections. Publicized market data invariably come from those who have ambitions to provide land mobile satellite services. There may be a tendency to paint rather rosy market pictures. Possibly it is part of a game of convincing those who need to be convinced--mainly investors, governments, and regulatory authorities--that the plans are worthy of positive responses. Whatever the reason, there are numbers out there which are at best optimistic and at worst glaringly inflated....

Because they receive such wide publicity, these numbers tend to be taken as gospel, are re-quoted as axiomatic, and finally become wrapped into the paradigm, the framework, within which decisions are made and the future of mobile satellite communications is mapped out.

As a satellite operator, I would be delighted if these enthusiastic projections proved out to be right. My fear, however, is that they are wrong, perhaps dramatically so.

Some of the inflated numbers appear to stem from simple misinterpretation of research data. So-called "potential markets" may represent markets for both satellite and

cellular systems, of which satellites will capture only a small amount. The difference between potential markets and paying customers can be one or two orders of magnitude....

I do not wish to come down too hard on the marketing research fraternity. Along with economists and marriage counselors, they practice an imperfect art. But I am convinced that the land mobile satellite market is simply not as large as some have made it out to be....

Mr. Lundberg went on to say that there is a role for land mobile satellite services, and that INMARSAT was determined to compete in that market, vigorously but realistically. [Ref. 61]

D. SYSTEM COST MODEL

This section will examine the relative user population and revenues required to recover system investment costs. Cost, volume, and profitability relationships will also be studied.

1. Background

Estimated system costs range from approximately $10 million for a nationwide meteor-burst system to around $800 million for the ultimate AMSC MSS configuration. System financing, leasing, incremental construction schedules, depreciation, tax rates, degree and speed of user adoption, average level of use, economies of scale, total revenues, and many other items will affect the ultimate cost and profitability of each system. A detailed financial model which takes these factors into account is beyond the scope of this thesis. However, a simple model can be used to make observations regarding the relative subscriber base and

average monthly fees required to recover the cost of the system. Gross profitability (revenues less amortized investment costs) at a given monthly fee and user base can also be modeled.

2. Model Development

As discussed earlier in the chapter and shown in Figure 74, construction of a terrestrial or satellite mobile communication system results in a series of cash outflows until the system becomes operational. The model shown in Figure 77 is a further simplification. This model assumes that the total cost of the system is incurred just prior to the start of the service. The only variable in this model is the number of subscribers, which starts at zero and increases at a constant rate until the end of the system design life. The receipts earned from each additional subscriber are also constant. Revenues earned by the system during the time period are equal to the number of users times the fixed revenue per user. Cumulative revenues up to any point in the system's life are equal to the area under the revenue line. This is equivalent to one-half the total number of users multiplied by the total revenues received during a time period. Geometrically, this is the same as the area of a triangle, which is one-half the base times the height.

The cost of the system is evenly amortized over its design life (straight line depreciation). As a result, the revenue required to recover the cost of the investment in any

Breakeven at End of Project Life

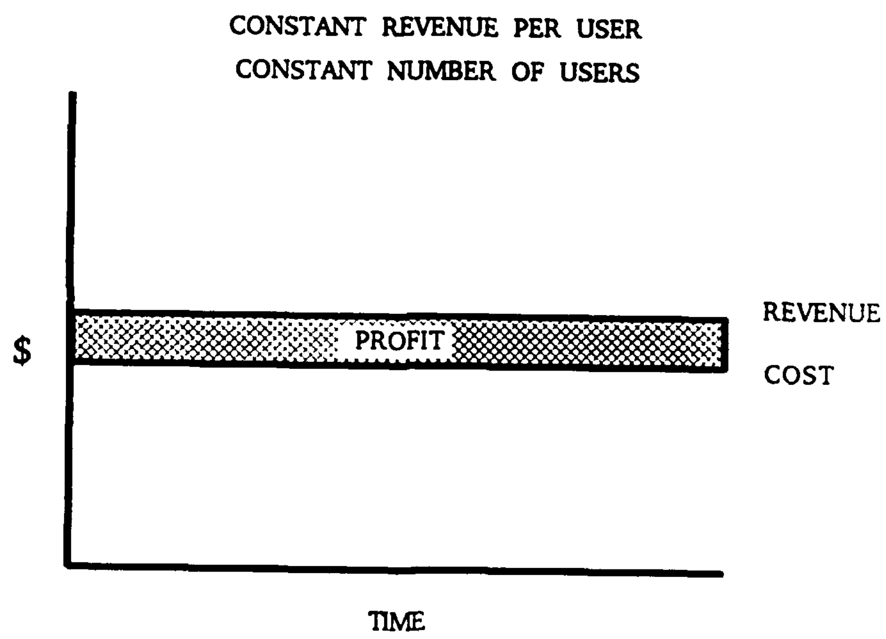

Figure 77. Breakeven at End of Project Life; Constant Revenue Per User, Constant Number of Users

time period will always be constant. Total system cost is equal to the area under the horizontal line, or dollars per time period multiplied by the number of time periods in the project life. Geometrically, this is equal to the area of a rectangle, or base times height.

The system will break even when the total revenues equal the total system cost. This occurs when the area under both the revenue and system cost lines is the same, and is shown on the graph where the system reaches break even at the end of the project life. Note that the average number of users occurs half-way through the project's life and is where the revenue line crosses the system cost line. The system will show a gross profit at the end of the project life if the area under the revenue line is greater than the area under the system cost line. If gross profits are higher than operating expenses, the system will show a net profit.

To further simplify the analysis, the number of users can be held constant. The constant number of users equals the average number of users in the linear growth model. This is shown in Figure 78, where the transformed revenue line is now horizontal and is overlaid on top of the system cost line. The average revenue per user required to recover the capital cost of the communication system is equal to the system cost divided by the number of users. The area under the revenue line is equal to the area under the system cost line, and once

BREAKEVEN AT END OF PROJECT LIFE

CONSTANT REVENUE PER USER

CONSTANT INCREASE IN THE NUMBER OF USERS

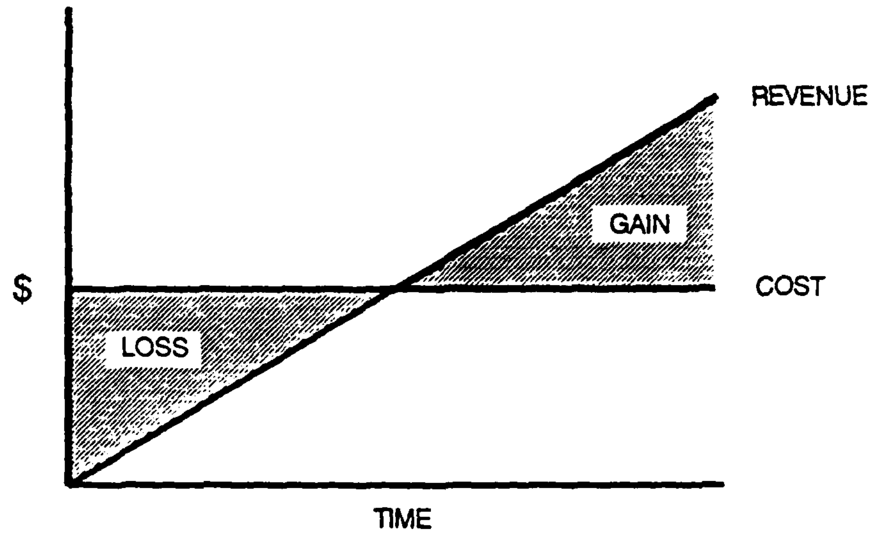

Figure 78. Breakeven at End of Project Life; Constant Revenue Per User, Constant Increase in the Number of Users

again breakeven is achieved. The system will show a profit if the revenue line is raised above the system cost line.

These illustrations show that a simple model of a system which will breakeven at the end of the project life can be represented by an average of its low and high-user population, so long as the user growth rate is constant and the revenue per user is the same. This simple relationship allows the various systems to be compared based on cost and average-user population.

3. Model Description

As illustrated in Figure 79, when the system cost is held constant and the average number of users is varied, a graph of the average cost per user (or average revenue per user required to pay off the system) forms a hyperbola. If a new system cost is selected and the number of users is again varied over the same range, a different hyperbolic curve will the result. The shape of the hyperbola shows how the average cost per user initially declines very rapidly as the number of users is increased. Past a certain point, additional increases in the number of users do not markedly decrease the average cost per user. This makes the graph difficult to read at relatively large user levels.

This difficulty is overcome by plotting the results on a graph which uses a logarithmic scale on both axes. As shown in Figure 80, this converts the hyperbola to a straight line. The revenue required over the life of the project to recover

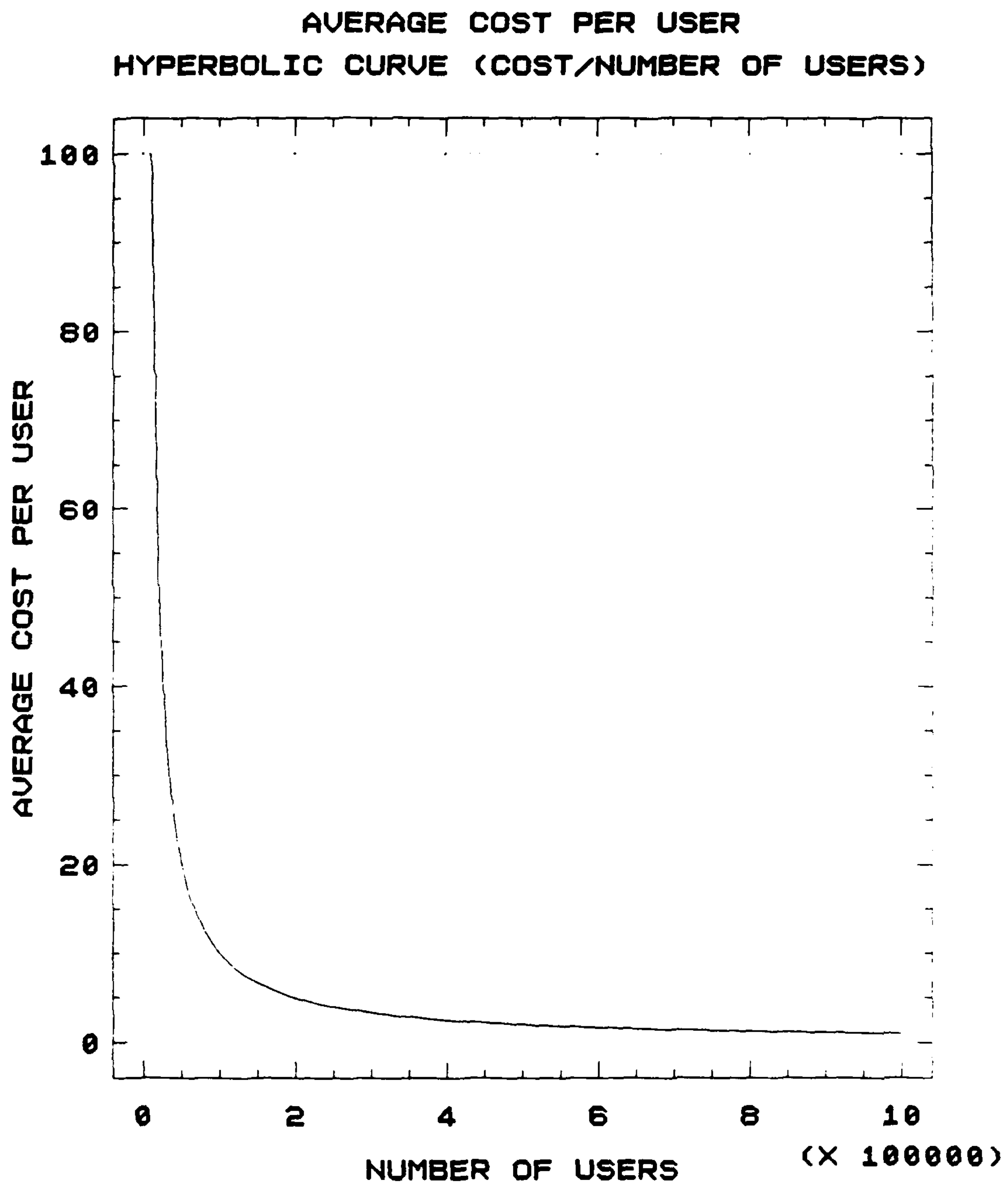

Figure 79. Average Cost Per User, Hyperbolic Curve (Cost/Number of Users)

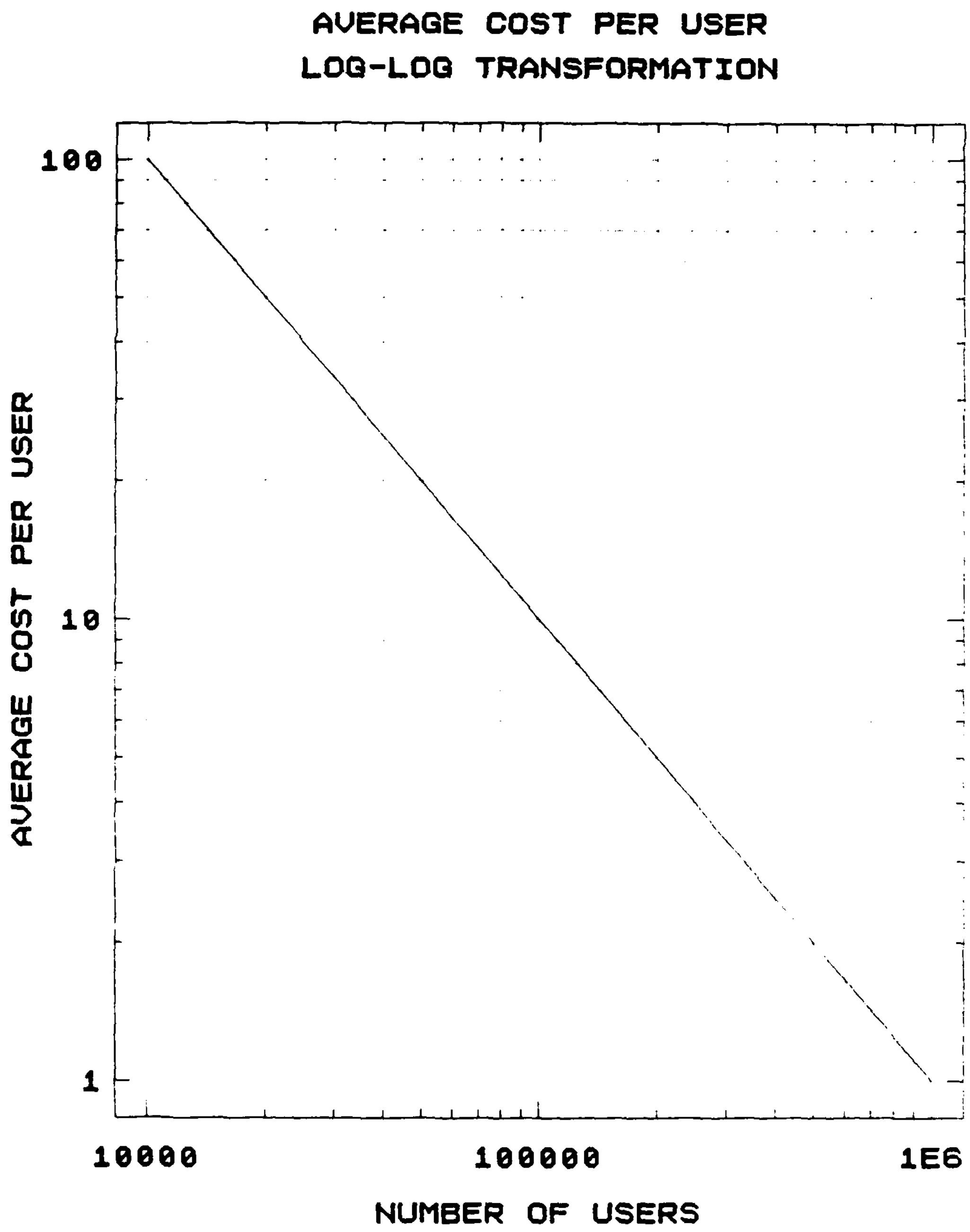

Figure 80. Average Cost Per User, Log-Log Transformation

the system costs at any average subscriber population can be read directly from the graph. To determine the monthly required revenue, the total average revenue per user is divided by the number of months in the system's life.

4. Model Assumptions

In order to determine the number of users and the monthly revenue required to recover system investment costs, the model assumes a one-time cash outflow is required for construction of the system immediately prior to the start of the service. To derive the equivalent investment cost for systems which use leased transponders, a ten-year series of constant monthly cash outflows is discounted at a rate of 12% back to the time of system implementation. The net present value of the cash outflows is treated as the system investment cost. A discount rate of 12% was selected based on the return which could be earned on an alternative and somewhat risky investment. Use of a lower discount rate raises the total system costs, conversely, a higher discount will lower costs.

Monthly revenues start immediately and run for ten years. Throughout this time the number of users and the monthly service fees are held constant. At the end of this period the system is paid off. Other than discounting the transponder leases to determine equivalent system investment costs, no consideration is made for the time value of money. Tax effects and expenses associated with operating and administering the system are also not considered.

Costs to implement nationwide SMR, cellular telephone, terrestrial mobile data, and paging system networks are proprietary and are not available. Table 24 lists the amounts assumed for meteor-burst and satellite systems. References for cost and capacity information are listed in Chapter II.

TABLE 24

SYSTEM COST ASSUMPTIONS

Meteor Burst	\$10 M. Capacity is 100,000 users per frequency pair.
Qualcomm OmniTRACS	Two Ku-band transponders leased at \$155K each per month at a five year lease rate. Equivalent investment cost is approximately \$21.61M. Capacity is up to 50K users per transponder pair.[3]
Geostar 2.0	\$50M outlay for two add-on transponder packages. Capacity is one million users.
Geostar 2C	System 2.0 costs (\$50M) plus one C-band transponder leased at \$125K per month on a five-year lease rate. Equivalent transponder investment cost is about \$8.71M. Capacity is up to 50,000 users per forward link transponder.[4]
Geostar 3.0	\$400M. Capacity is assumed to be a minimum of one million users.[5]

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[3]As discussed in Chapters II and VI, the FCC has only authorized 20,600 terminals. Qualcomm can request additional terminal authorizations.

[4]As discussed in Chapters II and VI, the FCC has only authorized 20,000 terminals. Geostar can request additional terminal authorizations.

[5]Actual capacity of an eight spot beam system is greater than one million users.

TABLE 24 (CONTINUED)

AMSC	\$730M. Capacity is assumed to be a minimum of million users (combined data and voice terminals).[6]

5. Model Output

The breakeven graphs shown in Figures 81 illustrate the number of users and monthly revenue required to recover system investment costs. Estimates of required user populations at different average revenue rates can be made by reading across from the y axis. The \$50 per month revenue line, which is roughly equal to the monthly Geostar and Qualcomm subscriber charge, is used as a benchmark to show the difference in user levels required for each system to breakeven. As intuitively expected, the lower the cost of the system, the lower the number of subscribers necessary to recover the investment costs. At the \$50 per month level over a ten-year period, meteor-burst systems will require approximately 1700 continuous subscribers to recover the investment costs. The Qualcomm leased transponder system breaks even at around 4500 users, and the Geostar 2.0 configuration needs approximately 8300 terminals. The Geostar 2C system requires approximately 9800 subscribers, while the Geostar 3.0 system requires an average user base of roughly 65,000. Under this model, the full AMSC system will need

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[6]AMSC forecasts that the system will become revenue constrained beyond the fifth year of operation.

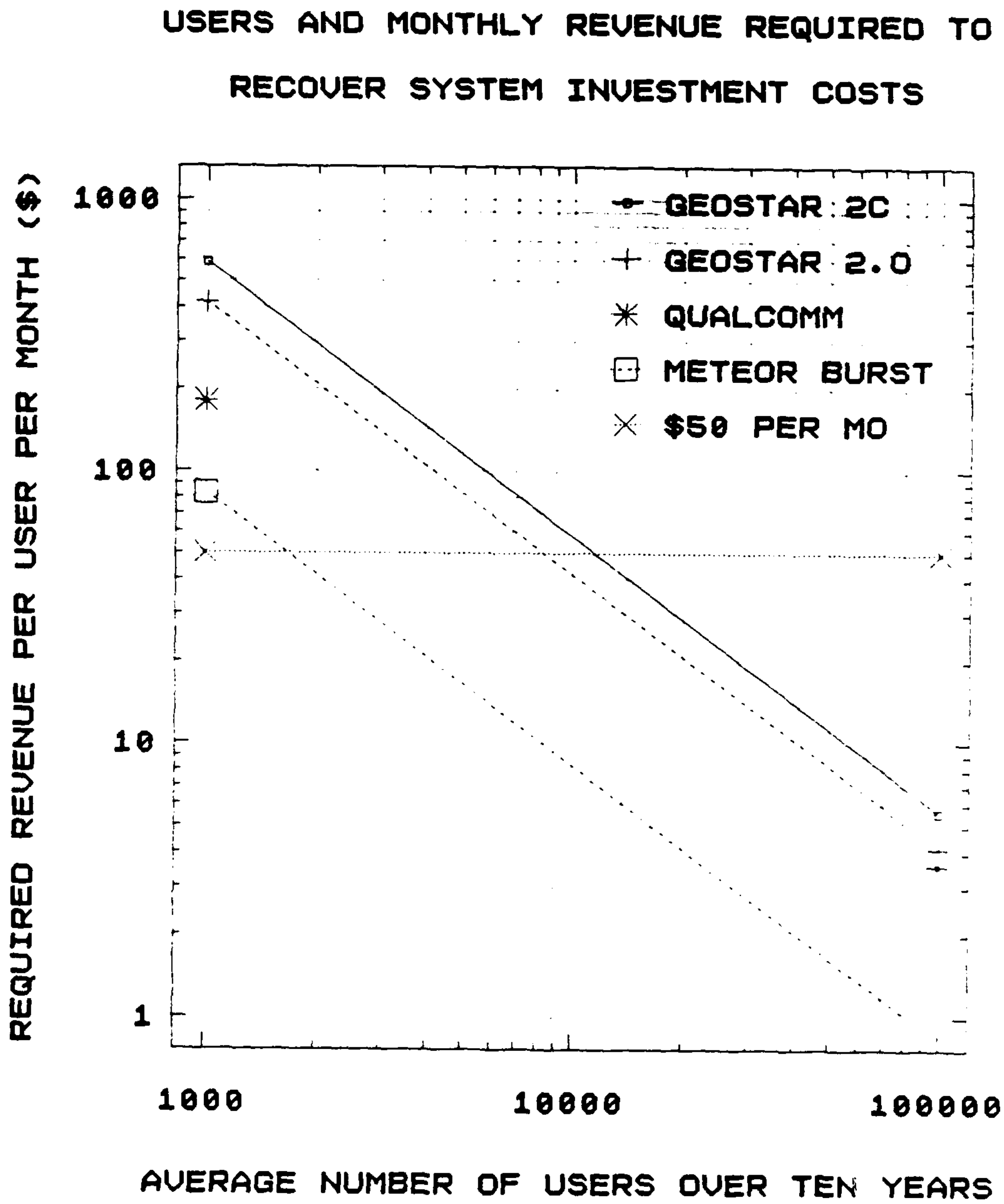

Figure 81. Users and Monthly Revenue Required to Recover System Investment Costs

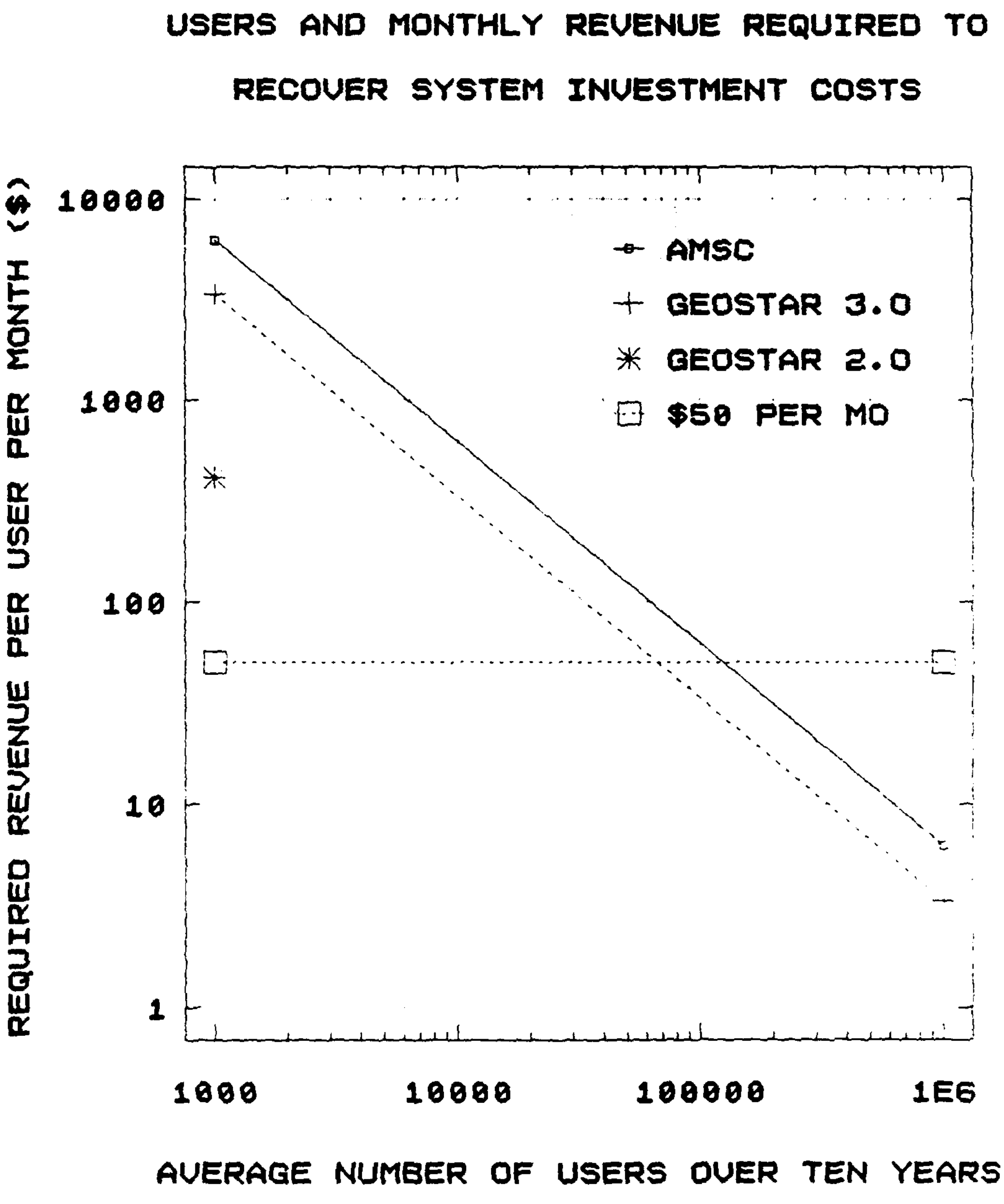

Figure 81. (CONTINUED)

about 125,000 terminals over a ten year period at $50 per month.

Gross profitability at different subscriber levels is illustrated in Figure 82. In this case, average monthly revenue per subscriber is fixed at $50 per month. Gross profit is determined by multiplying the total number of users by $50 per month and subtracting the monthly pro rata portion of the fixed system cost. The slope of the gross profit line is constant up to the point where the system becomes capacity constrained. Although not easily visible, adding additional units of capacity raises the total cost of the smaller size systems. This prevents the average cost per user from falling below a certain level and decreases the slope of the gross profit line.

6. Model Analysis

The breakeven model is based on an average number of users at a constant revenue per user over the project life. Forecast Geostar 3.0 and AMSC target markets exceed this level in the first year of operation. However, assuming the number of users will start off at a very low level and build almost constantly over time, the system will need double the average number of users by the end of the project life to breakeven. This relationship implies that significant negative cash flows could occur when the system is first available for use. As a result, system operators will be under a great deal of pressure to build a subscriber base as rapidly as possible.

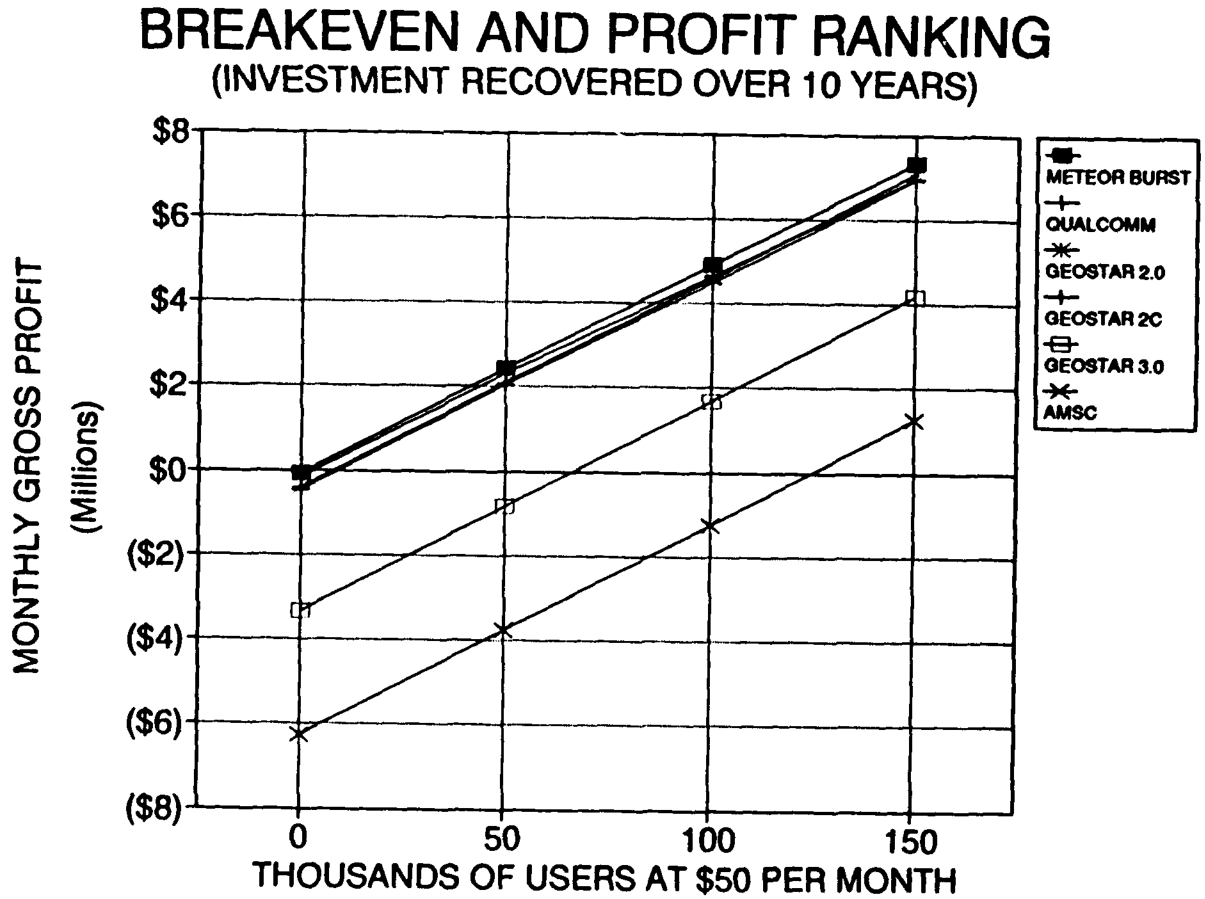

Figure 82. Breakeven and Profit Ranking (Investment Recovered Over Ten Years)

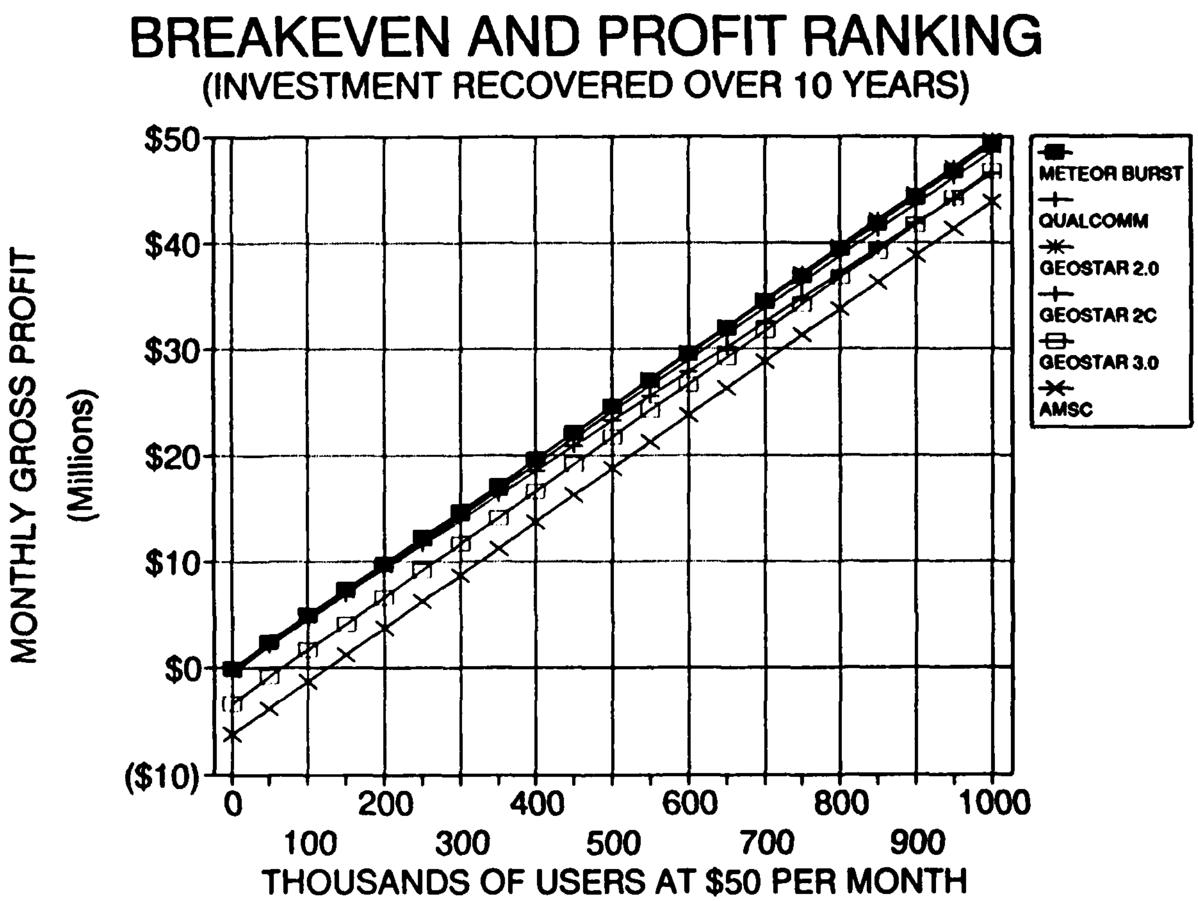

Figure 82. (CONTINUED)

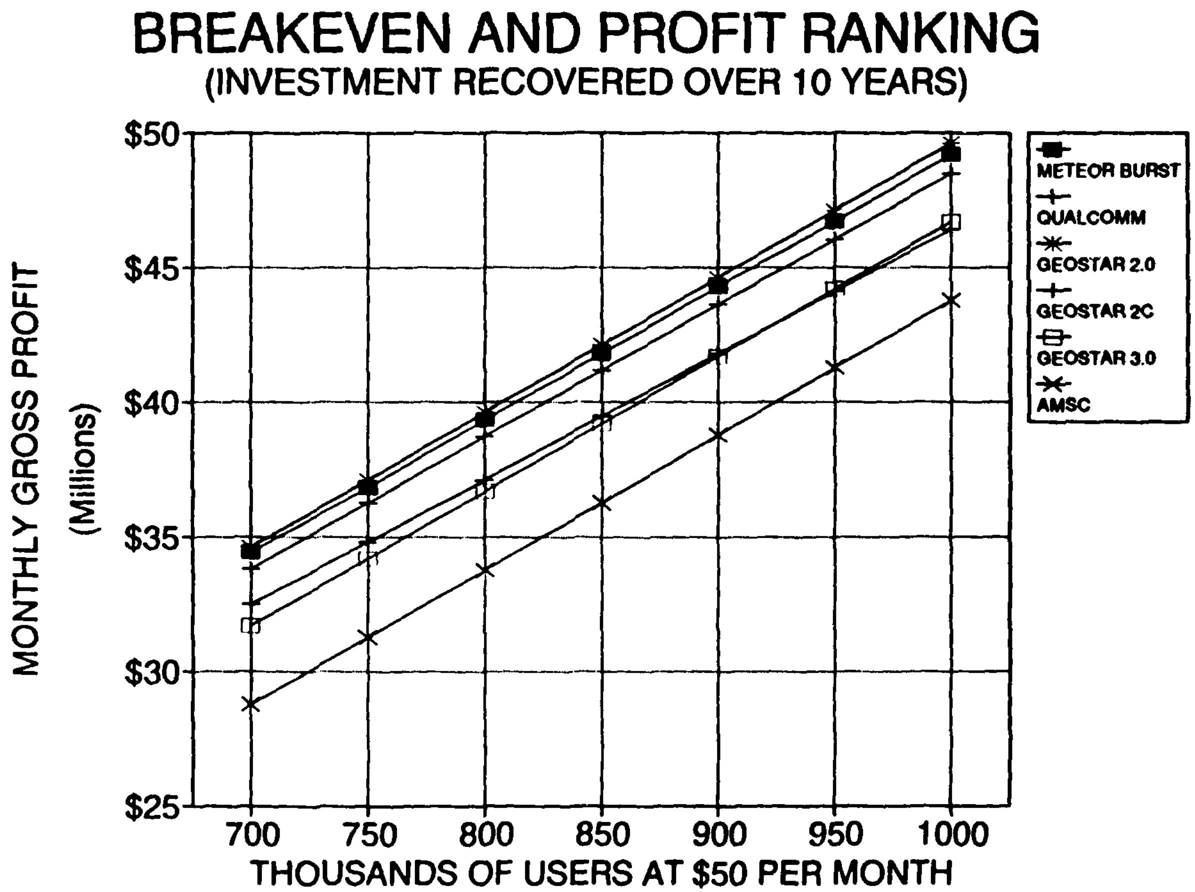

Figure 82. (CONTINUED)

As shown in Figure 81, this is particularly the case with the more expensive Geostar and AMSC systems. In part, their "early-entry" service offerings are designed to create a pool of subscribers which are available to use the system as soon as it is operational.

As is expected, the gross profitability graphs show that the lower the cost of the system, the lower the initial negative cash flows, and the lower the revenues or numbers of terminals required to breakeven. Conversely, the lower the system cost, the higher the profitability at any given subscriber level. This relationship holds true until the system reaches saturation. At this point, additional units of capacity have to be added, thus raising total system costs. Eventually the higher cost, higher capacity Geostar 3.0 and AMSC systems become more cost effective because of economies of scale. For example, under this model the lease expenses for 18 Ku-band transponder pairs is approximately equal to the monthly amortized cost of the Geostar 3.0 system. As shown in Figure 82, beyond this point (approximately 925,000 users at $50 per month) the dedicated Geostar system is more cost effective and profitable. This is because additional units of capacity do not have to be added until the system loading is in the millions of users.

In reality, the number of terminals required to recover the investment costs, pay the operating expenses, and generate a target profit will be greater than computed in this

simple model. Systems with relatively fixed pricing, such as Geostar, will tend to have a fairly constant and predictable revenue per user. Systems based on volume of use and communication mode, such as AMSC, will vary in the amount of revenue per user. This may result in average revenues greater than the $50 per month used in the gross profitability graphs, which will yield a faster payback and larger profits. For example and as calculated in Chapter III, forecast AMSC satellite telephone charges would be about $260 a month for 15 minutes of conversation per work-day.

The graphs show that the systems are highly leveraged. Once enough subscribers are obtained to recover the investment or transponder lease costs, the revenue from each additional subscriber is gross profit. Gross profits are used to cover the other fixed and variable costs of providing the service, such as the administrative and overhead expenses. Since these systems are automated, most of their operating costs will be fixed. As a result, a well-loaded system is capable of generating significant net profits.

Although nationwide SMR, cellular telephone, terrestrial mobile data, and paging networks are not modeled, certain economic comparisons and assumptions can still be made. Terrestrial communications systems do not have the same cost structures as space-based systems. Unlike satellites which are custom manufactured in small quantities and use comparatively exotic technologies, communication equipment for

terrestrial systems is produced on a much larger scale and uses relatively conventional technology. Terrestrial equipment can also be easily maintained and repaired. This avoids the extra costs associated with building satellites that must function reliably in the harsh environment of space for ten or more years. Terrestrial systems also do not have the burden of launch and insurance expenses.

With the exception of nationwide paging systems which use dedicated transmitters, these alternative systems already generate revenue from a local area subscriber base. The incremental cost for networking the terrestrial sites is the installation of additional computer hardware and software, plus the nationwide communications network charges. Terrestrial system operators will be encouraged to provide network and roaming services when the forecast extra revenue will be greater than the average costs of providing the service. This will most likely occur in the denser populated areas and transportation corridors. Although total incremental costs for this nationwide networking will be probably be less than constructing a dedicated $400 million to $800 million satellite system, average costs per user will depend on the number of roamers, communications volume, and other factors.

E. TRANSPONDER AVAILABILITY

The C-band transponders used in the Geostar 2C system, and the Ku-band transponders used by Qualcomm were not intended for mobile communication use. Instead, they were designed for video, audio, and data transmission between fixed earth stations. As shown in Figures 83 and 84, demand for these transponders continues to rise [Ref. 62].[5]

The "authorized" quantity of transponders is estimated based on FCC approvals for satellite design and assignment of orbit locations. The "probable" quantity of transponders is an estimate of what will actually be in orbit, and is based on satellite economics and market demand. The quantity of transponders fluctuates because satellites have a design and service life. To prevent an interruption of service, new satellites must be launched before old satellites are retired to a parking orbit. This accounts for the peak numbers of transponders in the early 1990's.

In this forecast, the C-band demand for transponders is expected to grow at approximately 3% per year, while Ku-band is expected to increase at around 16% per year. Based on these projections, demand for transponders is expected to exceed the supply in the 1994 to 1997 timeframe. Assuming these forecasts hold true, more authorized satellites will be launched or the price of transponders will rise. A

[5]Information provided was excerpted from proprietary reports.

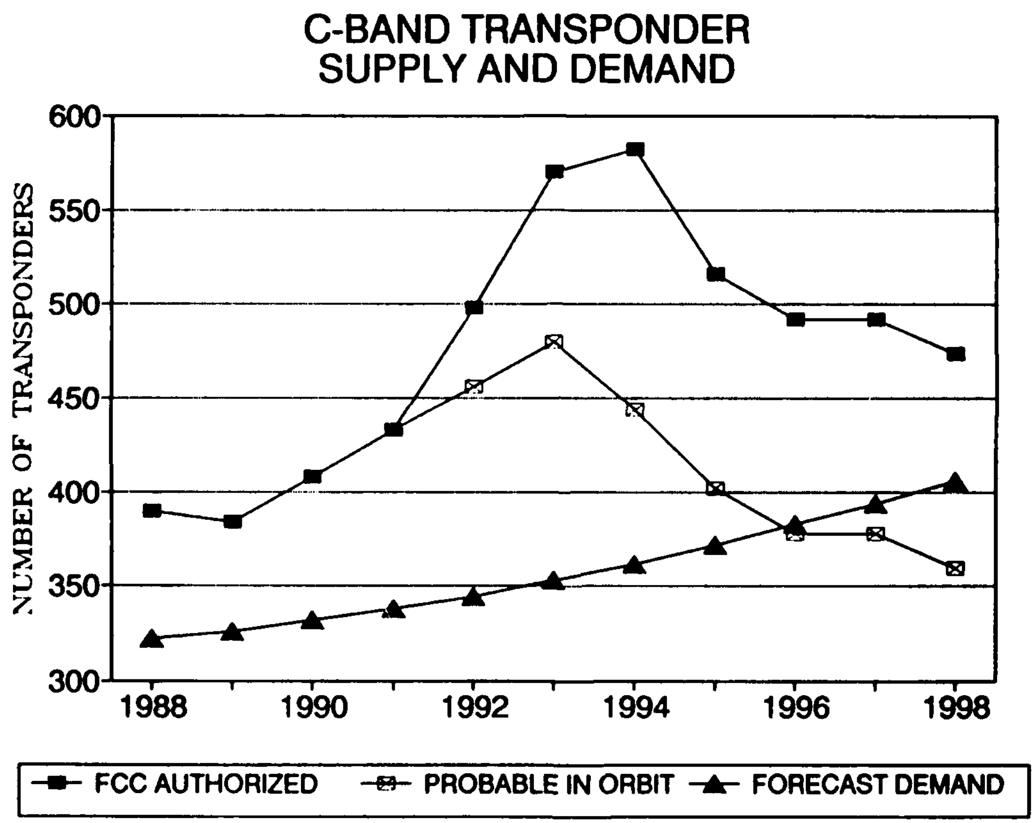

Figure 83. C-Band Transponder Supply and Demand

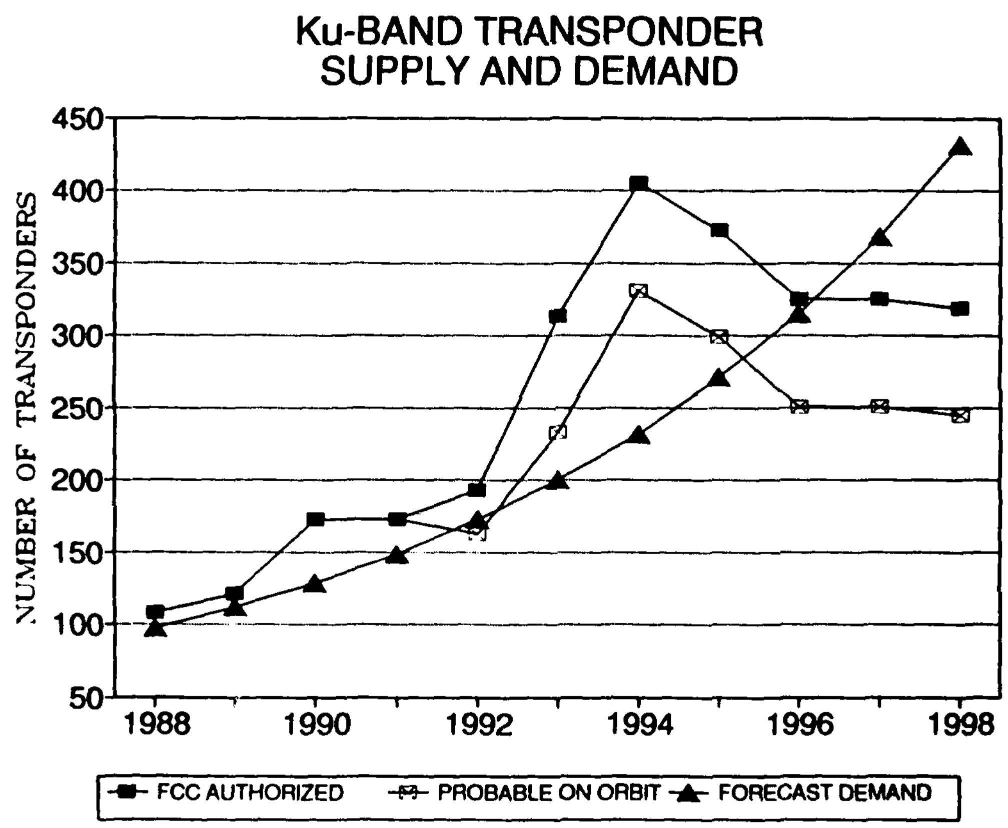

Figure 84. Ku-Band Transponder Supply and Demand

combination of both may also be likely. Restrictions in supply or price increases could limit the long-term expansion plans of mobile communications systems which rely on conventional transponders.

F. GEOLOCATION SYSTEM COST TRADEOFFS

The Geostar, Qualcomm, and meteor-burst systems discussed above provide remote position determination in addition to mobile communications. Other systems, such as INMARSAT, AMSC, TMI, Geostar DLMSS, and Motorola CoveragePLUS offer geolocation as an option. Geostar 3.0 and Qualcomm Automatic Satellite Position Reporting (QASPR) utilize satellite ranging. All other systems (including Geostar 2.0, 2C, and earlier Qualcomm terminals) rely on a radionavigation receiver for geolocation. These two separate position reporting methods add to the complexity and expense of each system. As a result, systems providing geolocation can be thought of as having separate cost components for communication and position determination.

As discussed in Appendix B, satellite ranging uses signals relayed via two or more satellites, and the terminal's location is calculated based on time of arrival differences. If the return link on one satellite were to fail, communications could still take place but ranging could not be accomplished. In the case of Geostar 3.0, this requires that a third satellite be orbited, which raises the fixed cost of

the system by around $75 million to $125 million (which includes the cost of the satellite, launch, and insurance). In Qualcomm's case, communication and ranging redundancy are obtained by being able to shift the system over to other transponders on the same or a different satellite. Leasing a portion of a Ku-band transponder on a second satellite for ranging increases Qualcomm's fixed monthly operating costs. Since ranging capability increases the costs of both systems, the number of subscribers determines the average geolocation cost per user.

The situation is different for systems which incorporate Loran-C, GPS or Glonass radionavigation receivers. Although some governments usually bear the cost of providing the radionavigation service, the expense of including the additional radionavigation circuitry in the terminal is borne directly by the user and is a sunk cost over the equipment life. As a result, once the equipment is bought, the number of other subscribers has no bearing on the user's amortized terminal cost and geolocation expenses. However, with production economies of scale and continuing technological improvements, subsequent radionavigation circuitry should continue to fall in price. This is evidenced by the cost of Loran-C receivers, which could be bought for as low as $400 in

1989.[7] A hand-held GPS receiver was also available at that time for around $3000, and GPS integrated circuit sets are expected to fall to around $200 as production volumes markedly increase [Ref. 63]. These price reductions over time should reduce the cost of terminal production.

Figure 85 is a simple model which illustrates the cost and volume relationship between satellite ranging and radionavigation receiver circuitry. The model assumes the level of accuracy provided by each ranging system is acceptable to the user. Only the space segment expenses are considered, since it is assumed that the terminal and NMC use additional software and hardware which do not dramatically increase the system costs. The cost of a $100M satellite used for ranging is amortized over a ten-year period based on the average number of users. Also, it is assumed that one-half the bandwidth of a Ku-band transponder is used to relay the ranging signal transmitted by the Qualcomm NMF. Since the signal can be received by <u>all</u> mobile terminals within the coverage area, there is no capacity constraint on this communications path. A ten-year series of $77,500 monthly lease payments (one-half the cost of leasing a Ku-band transponder at the five-year lease rate) is discounted at a rate of 12% back to the time of system implementation. This

[7]Interview between Mr. Tom Carpenter, marine electronics distributer and installation engineer, Newport Beach, Ca, and the author, May 1989.

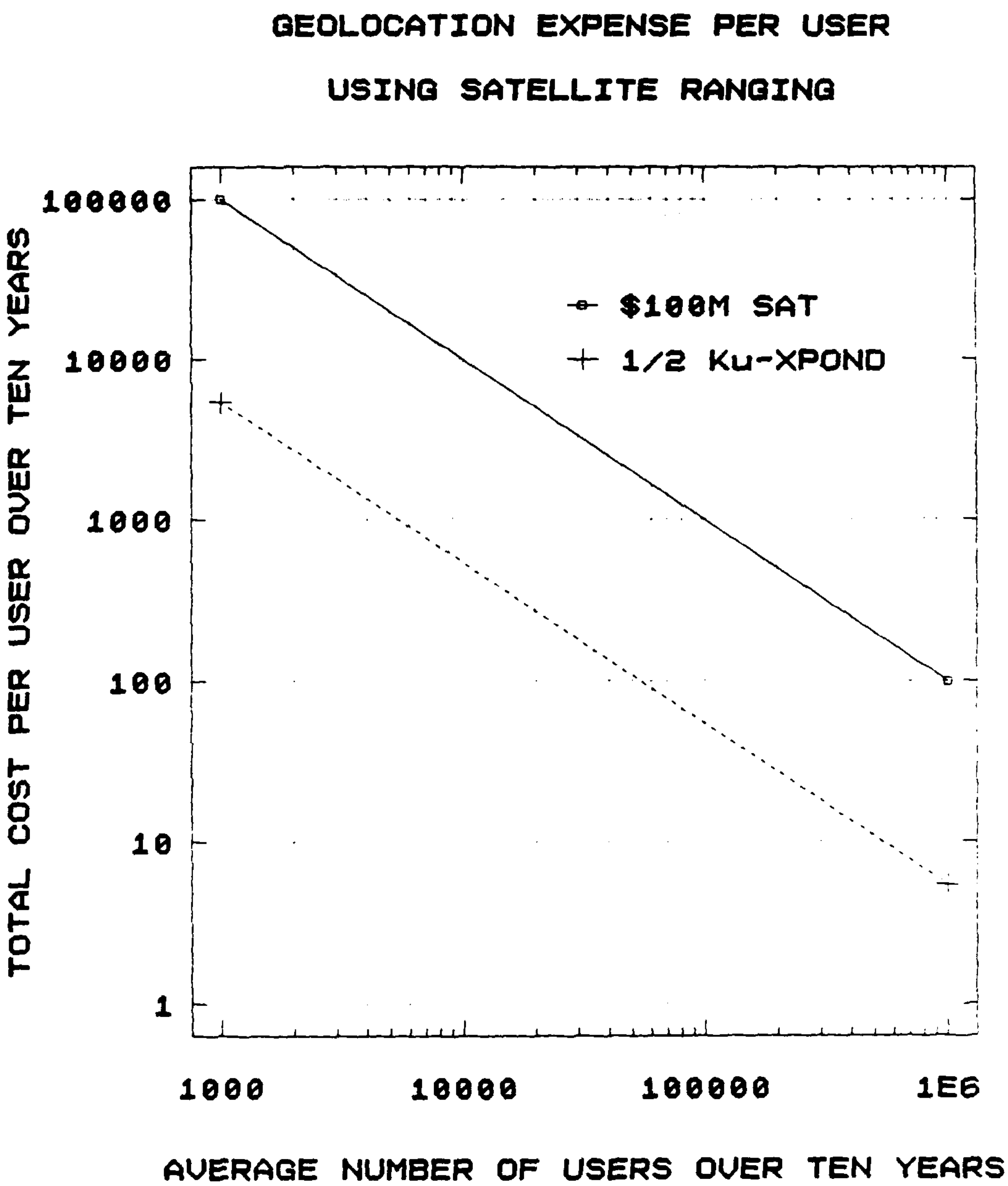

Figure 85. Geolocation Expense Per User Using Satellite Ranging

produces an equivalent transponder investment cost of around $5.37M.

The geolocation cost per user is read on the y-axis. If at a given terminal population the additional cost for radionavigation receiver circuitry is below the amortization line, then ranging is more expensive. Conversely, if the cost for the additional circuitry is above the line, ranging is more cost effective.

For example, assuming all geolocation costs will be passed on to the users, a GPS receiver which adds $3000 to the price of a terminal will be as expensive as the cost of the satellite distributed for ten years over an average of about 33,300 users. Assuming one-quarter mile accuracy is acceptable, a $400 integrated Loran-C receiver is equivalent to the satellite cost distributed over 250,000 users. This also equals the cost of the Ku-band system distributed over about 13,500 users. If GPS chip sets drop to $200 as predicted, the cost of the extra satellite would have to be amortized over 500,000 users to break even, and the Ku-band system would requir 27,000 subscribers. Model sensitivity is easy to judge. Doubling the costs of ranging will cause the breakpoint to double, and halving the price will reduce the breakpoint by 50%. The opposite holds true for volume and time.

This model illustrates that a ranging system which uses a leased transponder to broadcast a ranging signal does not

require a large terminal population to be economical. Conversely, a dedicated satellite requires a substantial terminal population over the satellite life or the ranging cost per unit will be greater than using an integrated radionavigation receiver. This particularly holds true if Loran-C is available and the level of accuracy (1/4 mile) is acceptable. As the cost of manufacturing GPS receivers declines due to production volumes of scale and improving technology, the equivalent number of GPS receivers to breakeven will also expand. However, these breakpoints are less than 50% of Geostar 3.0's user capacity.

Ideally, geolocation will be performed with an acceptable level of accuracy and at the lowest total expense. Suppliers desire to maximize the return on their investment by stimulating user demand through affordable costs, and users are obviously interested in minimizing their equipment and monthly service fees. With satellite systems which are capable of ranging, both of these seemingly opposite goals can be achieved by properly structuring the geolocation system according to the size of the market.

G. CHALLENGES FACED BY RDSS AND MSS SYSTEMS

1. Background

As discussed previously, the providers of satellite-based mobile communications systems face the challenges of an uncertain market size and growth rate. In this type of

environment, systems which use satellite add-on packages and leased transponders are the least risky because their incremental costs are low. As modeled above, to recover the investment in these lower-cost systems requires an average of less than 10,000 terminals over ten years at $50 per month per user. On the other hand, dedicated satellite systems have much higher incremental costs, which helps to raise the breakeven point to around 65,000 terminals for Geostar 3.0 and 125,000 for AMSC. However, dedicated systems are not constrained by transponder availability and pricing, and can be very profitable with large user populations.

As discussed below, the challenges faced by the operators of these systems will be to obtain a user base quickly enough to make the systems economically viable, and particularly in Geostar's case, to drive total user costs downward to stimulate additional demand.

2. Market Categories

The potential satellite user market can be divided into roughly two categories. One category of user requires satellites, either because no other communication option is available, or the characteristics of satellite communication (ease of use, uninterrupted coverage, quality-of-signal, etc.) are desired. Users in this category will consider the use of satellites to be mandatory as long as the costs are considered reasonable or the economic return is favorable. An example would be a nationwide trucking firm which, despite relatively

high initial terminal costs and monthly fees, earns a positive return from its use of satellite communications and tracking.

The second category consists of discretionary users who are not strictly bound to satellites for their communications or who are very price sensitive. An example of this category would be a rural resident who would like a satellite car phone but considers the cost unreasonable.

3. Fully Allocated Costs and User Demand

Figure 86 is a graph of the approximate business demand curve contained in the 1985 Omninet RDSS proposal[7] [Ref. 54:p. 28]. This curve has an increasing slope as the fully-allocated monthly costs (charges for equipment and service) decrease. This demand curve is similar to the cellular radio demand curves shown previously in Figure 17. These graphs imply that fully-allocated business user costs of less than roughly $100 per month are required to capture large portions of the potential satellite and cellular market. The personal use demand curve is probably more sensitive to price at all levels.

When evenly amortized over five years at a 12% cost of capital, the $4100 Geostar 2C and Qualcomm satellite mobile data equipment costs about $91 a month. When added to monthly service fees and long-distance connect charges of about $50 a month, this totals to roughly $141 for data only

[7]These figures are not adjusted for inflation.

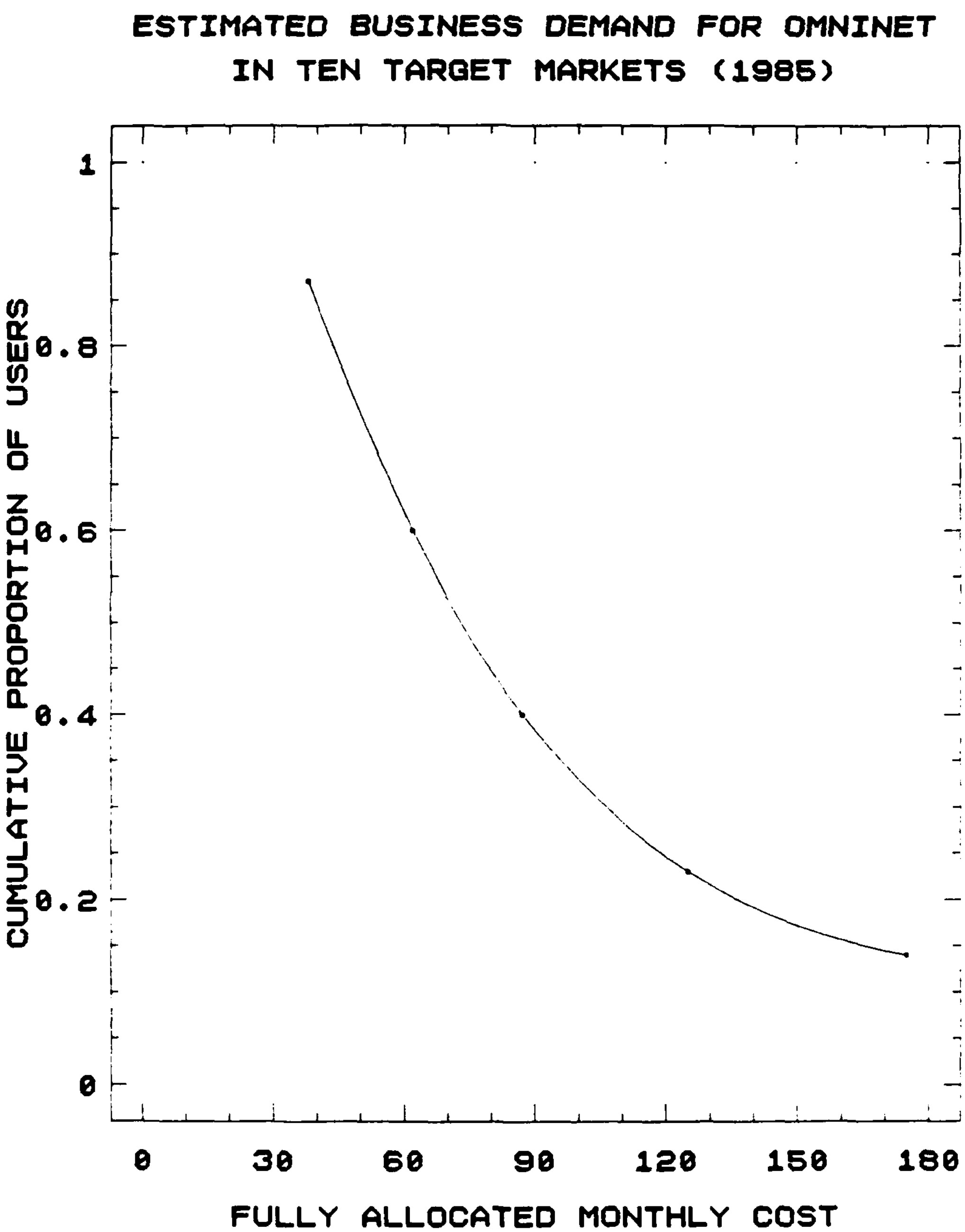

Figure 86. Estimated Business Demand for Omninet in Ten Target Markets (1985)

communications. Initial fully allocated costs for Geostar 3.0 would be near this level.

Mobile satellite voice, with its less efficient use of the spectrum, will cost more. However, because of convenience and other factors, it will appeal to user groups which are <u>not</u> interested in communicating via a keyboard display unit. As computed in Chapter III, in 1988 AMSC estimated that satellite telephone service using a $3500 terminal and five minutes of conversation per work-day would cost around $191 per month. Talking for 15-minutes per work-day would raise the monthly price to roughly $365.

As discussed in Chapter III, each terminal cost increment of $1000 amounts to about $22 a month when amortized over 60 months at a 12% cost of capital. When combined with monthly service fees, initial terminal prices of $3000 to $4000 will force the fully allocated expenses into a region of the demand curve which is relatively inelastic. In this area, a percentage reduction in communication or equipment charges will not generate a corresponding increase in user demand. The users located on this region of the curve will be the ones for whom satellite communications is mandatory or strongly desired. If the population of this group is large enough, then significant monthly revenues, terminal sales, and system loading should result.

Since most, if not all, of the revenues will be required early on to recover the space segment investment,

system operators will probably not be inclined to drastically lower their basic charges over the short run. As a result, most of the initial downward reductions in fully-allocated costs will probably come from terminal manufacturer competition and production economies of scale. If continued long enough, eventually the downward movement in fully-allocated cost should reach a point where the demand curve becomes more elastic. In this region, a percentage reduction in the fully-allocated user cost will spur correspondingly greater increases in supplier revenues. At this point, discretionary users will begin to subscribe to the service in increasing numbers. As shown previously in Figure 20, this was partially the case in the cellular telephone industry between 1983 and 1988, where telephone cost reductions were responsible for a large part of the decline in fully-allocated costs. This appears to be the setting under which Geostar predicted millions of users would ultimately be served by system 3.0 and DLMSS.

This scenario is illustrated in Figure 87. The fully-allocated supply cost is the sum of the amortized terminal expenses and fixed monthly communication charges. The supply line is horizontal because communications capacity is constant in the short run. Total system revenues are equal to P_1 times Q_1. Sufficient user demand generates production economies of scale, which reduces mobile terminal costs. Supply cost

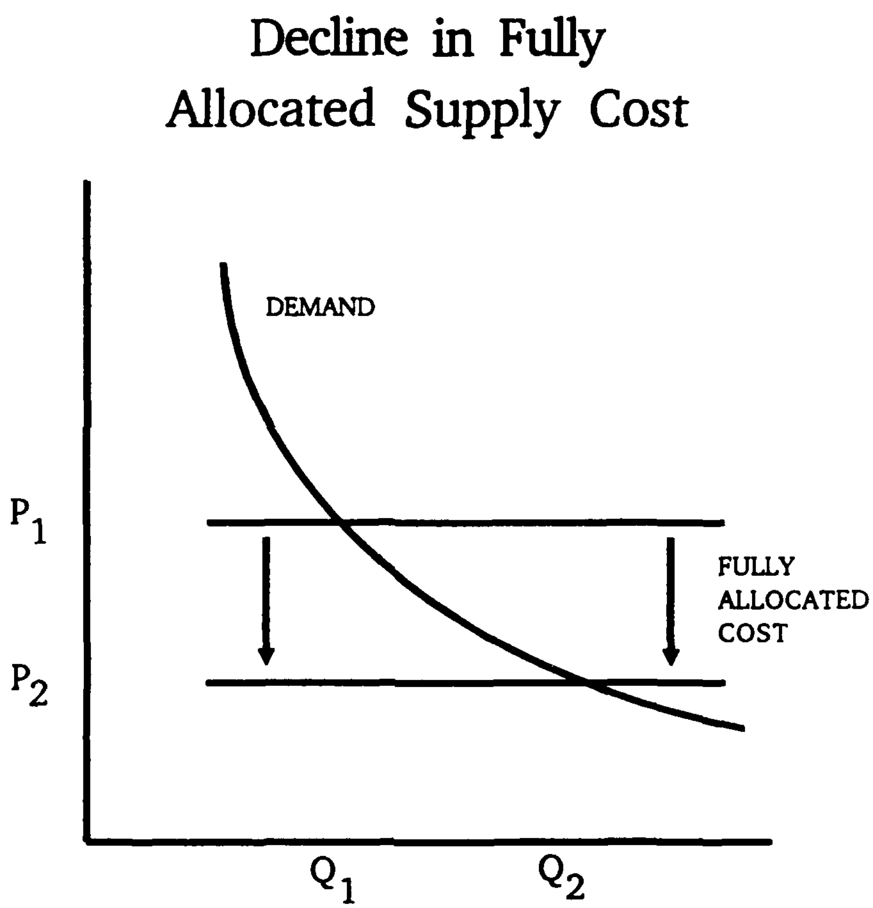

Figure 87. Decline in Fully-Allocated Supply Cost

shifts downward from S_1 to S_2. When this occurs, the quantity demanded and total revenues increases. Ideally, the cycle repeats itself, and both supplier and user benefit.

However, system operators could find themselves in an unfavorable situation if the size or growth rate of the initial market is not large enough to generate adequate revenues and terminal production economies. The options will be to increase user awareness (attempt to shift the demand curve to the right), decrease the user's fully-allocated costs by reducing communication charges, subsidize the cost of terminals in some manner, or a combination of all three.

4. Fully Allocated Cost Conclusions

The short-term viability of expensive, dedicated systems is dependent on the initial size and growth rate of the market which is willing to pay the higher initial costs. Assuming revenues from this market do not greatly exceed the breakeven point, long-term profitability will become primarily dependent on the reduction of the user's fully-allocated cost. This may not be an issue in the case of AMSC, which expects to be revenue-limited after the fifth year of operation. For Geostar 3.0, which has projected monthly RDSS fees per user to be less than $50, major decreases in fully-allocated costs can realistically only come from reductions in the price of terminals. However, very significant production economies could occur since system 3.0 has a capacity of several million

users and it shares a common standard with the planned European Locstar system [Ref. 64]. Common worldwide standards for regional and domestic MSS systems would also enable production economies to be achieved sooner than if systems are incompatible.

H. SUMMARY

1. U.S. Market Size and Revenues

The market estimates contained in the Geostar 3.0, Geostar DLMSS, and AMSC proposals submitted to the FCC total approximately 7.1 million terminal units. AMSC was the most conservative in its forecast of about 1.1 million units. The Geostar 3.0 and DLMSS terminal estimates were roughly 3.5 million and 3.0 million, respectfully. Forecast revenues amount to about $6.7 billion over the life of the three systems.

Taken together, these estimates triple count the use of satellite systems by the long-haul trucking industry. Additionally, the Geostar estimates made in 1985 and 1988 include providing existing and new services within areas already served by terrestrial communications systems. These estimates probably did not take into account the dramatic and continuing growth of terrestrial systems which could be networked on a nationwide basis. Schedule delays have also contributed to losing some potential user groups to

terrestrial systems. As a result, these combined market-size figures are most likely over-optimistic.

2. System Costs and Profitability

The majority of RDSS and MSS system costs are fixed, and consist primarily of recouping the ground and space segment investments. As a result, these systems are highly leveraged. Once the fixed costs in the accounting period are recovered, most of the remaining revenue is gross profit. Very high net profits can be realized if these systems are operating near their capacity.

Lower-capacity satellite mobile-data systems use satellite add-on packages and leased transponders. These systems have a lower cost structure, which allows them to be more profitable with a reduced user population. Assuming additional units of capacity are available, these systems can be expanded incrementally when they near communication traffic saturation. In contrast, dedicated RDSS and MSS systems have much higher incremental costs. However, dedicated systems have greater communication capacities and can offer a broader range of services. Dedicated systems can also be much more profitable with high user populations because their fixed costs are distributed over many more users.

3. Challenges Faced by RDSS and MSS Systems

Aside from meteor-burst, the only commercial mobile communication option in sparsely populated areas is RDSS and MSS. This is also the case where continuous nationwide

coverage is required. Mobile satellite-service providers face uncertain market size and growth rates because of the continuing expansion of terrestrial systems and the relatively high fully-allocated user costs. In this environment, satellite add-on packages and transponders have the least economic risk because their incremental costs are much lower than dedicated systems. However, these lower-cost systems provide a narrower range of services and cannot relay voice communications.

The very high incremental costs for dedicated RDSS and MSS satellites can result in significant negative cash flows when the systems first enter operation. As discussed above, regulatory and other delays will cause some of the potential U.S. market to be lost to alternative terrestrial, meteor-burst, and satellite mobile-data systems. As a result, dedicated RDSS and MSS systems will be under pressure to build an initial base of users as rapidly as possible. This is the primary reason for interim services.

Fully-allocated user costs will play a major factor in the size of the market. Introductory costs for terminals will be $3500 or more. Because of this high initial expense which is added to monthly service fees and communications charges, a percentage reduction in fully-allocated costs will not generate a greater increase in system use. As a result, system operators will probably not initially be inclined to reduce their service charges because the cash flows are needed

to recover the cost of the investment. Most of the cost reductions will come from competition between terminal manufacturers and production economies of scale. If worldwide MSS operating standards can be agreed on, than users should benefit from faster declines in terminal prices.

The high initial terminal and operating costs will limit most mobile satellite uses to business applications. Assuming the rural and mobile market segments are large enough, RDSS and MSS systems will not have to drop drastically in price to be successful. Should fully-allocated costs fall to around $100 per month, a given percentage reduction in expenses will spur a correspondingly greater increase of use. At this price level, mobile satellite communications would become a consumer item. Even at this cost level, operations in the more densely-populated areas, and in situations where continuous coverage is not required, will be subject to price and service competition from lower-cost terrestrial systems.

VI. REGULATORY HISTORY OF MOBILE SATELLITE SYSTEMS

A. INTRODUCTION

Like land, radio-frequency spectrum is a limited resource. In the early days of radio there was not much frequency congestion and little need for regulation. Improvements in technology, new uses for radio, and increasing demands for spectrum required that regulations be designed to prevent stations from interfering with each other. Like suburban expansion, some of the spectrum pressures have been reduced as improvements in technology permitted radio communications to take place at increasingly higher frequencies. The scarcity of additional spectrum also prompted the development of multiple-access methods, frequency reuse, and advanced types of modulation to "build up instead of out." These approaches permit the same frequencies to be shared by more than one user without causing mutual interference. The need for regulation and frequency coordination has grown over time partly because of these issues.

New types of communications systems must obtain frequency allocations before they can become operational. Frequently, this involves petitioning a regulatory agency to remove or reduce some organization's preexisting "right" to use a portion of the rf spectrum. Technological and economic review of two or more competing system designs may also be required.

This technical, legal, and political process invariably takes time, particularly if the proposed action would have international ramifications. Proponents of new or expanded systems often view this regulatory process as a major barrier to system implementation [Ref. 65].

B. REGULATORY AGENCIES

Since radio waves do not respect international boundaries, a United Nations organization known as the International Telecommunications Union (ITU) provides the basic regulatory framework for each of the three ITU regions (North and South America are contained within Region Two). Delegates from member countries gather at periodic meetings, known as World Administrative Radio Conferences (WARCs), to decide on frequency allocation and other related issues.

Each country also has one or more regulatory bodies which are responsible for the oversight of radio-frequency activities within its borders. Use of the spectrum within a country will generally comply with the ITU frequency allocations. Nonconforming use of spectrum may be authorized providing that it does not result in harmful interference to conforming uses of the band [Ref. 66:Ch. 3, Art. 6, Sec. 4 (no. 342)].

C. REGULATORY HISTORY OF MOBILE SATELLITE SYSTEMS BETWEEN 1971 AND 1979

In 1971, the International Telecommunication Union (ITU) met in Geneva to establish a general conceptual and regulatory

framework for satellite communications. At the meeting, known as the World Administrative Radio Conference for Space Telecommunications, several important agreements were adopted. Member states agreed that all countries shall have "equitable access" to the geostationary orbits and the allocated satellite frequency bands. A comprehensive set of definitions was adopted which listed all possible satellite services, one of which was the use of satellites to remotely determine the position and velocity of an object [Ref. 8:pp. 19-20]. This concept was named the "Radio Determination Satellite Service" (RDSS) and defined as "The determination of the position, velocity, and/or other characteristics of an object, or the obtaining of information relating to these parameters, by means of the propagation properties of radio waves" [Ref. 66:Art. 1]. The Mobile Satellite Service (MSS) was defined as "radio communications service...between mobile earth stations and one or more space stations,...or between mobile earth stations by means of one or more space stations." Land Mobile Satellite Service (LMSS) was defined as "a mobile-satellite service in which mobile earth stations are located on land." The Aeronautical Mobile Satellite Service (AMSS) and Maritime Mobile Satellite Service (MMSS) received similar definitions [Ref. 66:Arts. 27, 29]. Frequencies were allocated to the AMSS and MMSS at the Maritime WARC, which was also held in 1971 [Ref. 67:p. 140].

The interval between the 1971 Maritime WARC and the 1979 WARC saw the creation of INMARSAT (discussed in Appendix A) and the demise of a proposed AMSS system called Aerosat [Ref. 67:p. 140]. The General World Administrative Radio Conference held in 1979 did not receive any frequency allocation requests for RDSS. However, the conference did allocate new frequencies to the Radio Navigation Satellite Service (RNSS). The RNSS was allocated at the request of the United States, which intended to use it for the Global Positioning System (GPS) [Ref. 8:p. 20]. Recognizing that the AMSS frequency allocation would remain unused for some time while the demand for MMSS capacity would increase, the conference also adjusted the two allocations, giving additional spectrum to the maritime service at the expense of the aeronautical service [Ref. 67:p. 140].

D. FEDERAL COMMUNICATION COMMISSION RULINGS ON RDSS

1. System Standards and Licensing

In 1982, Dr. Gerard K. O'Neill obtained a U.S. patent (No. 4,359,733 containing 49 claims) for a satellite air-traffic control and collision system [Ref. 68]. This system was named the "Triad" because of its reliance on a three-satellite triangulation system. O'Neill formed the Geostar Corporation in 1983, and on 31 March of that year filed several applications with the Federal Communications Commission (FCC) for the authority to construct, launch, and

operate four satellites in the radiodetermination satellite service [Ref. 8:p. 21]. One satellite was to be an in-orbit spare. Simultaneously with the submission of its applications, Geostar petitioned the FCC to begin a rulemaking to allocate frequencies for this system [Ref. 69:p. 651].

On September 7, 1984, the FCC issued a Notice of Proposed Rulemaking (NPRM) and an accompanying public notice accepting Geostar's application for filing and inviting other applications to be filed for concurrent consideration. Extensive comments were filed on both the frequency allocation and licensing portions of the rulemaking. Finding a public need for RDSS, the FCC, on 25 July 1985, allocated frequencies for use by the radiodetermination satellite service. A subsequent Report and Order adopted policies and procedures for licensing RDSS systems. [Ref. 69:p. 651]

In the NPRM, the FCC stated that it did not propose to prohibit any ancillary or incidental message service provided that the primary purpose of the satellite is to provide radio-determination. The NPRM adopted Geostar's general design as a baseline to provide a point of reference to other applicants. The baseline did not contain specific technical parameters but proposed only a generic random-access time division multiplex (TDM) technique as a means of accomplishing multiple entry.

> The Commission stated that multiple entry appeared technically feasible, and would benefit the public by allowing competition in the provision of RDSS. This policy

might also make it possible to avoid conducting comparative evaluations of the applicants or establishing other processing procedures, and would allow a wide variety of RDSS offerings to be made available without delay. Comment was therefore solicited on the feasibility of licensing multiple systems to operate in the proposed spectrum. The Commission noted that the Geostar design appeared to allow several independent systems to operate, and required RDSS applicants proposing different technologies to demonstrate how multiple systems could be accommodated under their proposals. [Ref. 69:p. 653]

Four RDSS applications, including an amended application by Geostar, were filed in response to the NPRM. Three applicants, Geostar, MCCA American Redetermination Corporation (MARC), and McCaw Space Technologies (McCaw) proposed systems employing spread-spectrum techniques to transmit digital data. The fourth, Omninet, proposed a system using a different technology to provide two-way voice communications. Radiodetermination service would be provided by relaying GPS position information to users. Omninet's narrow-band frequency division multiple-access (FDMA) technology, which allocated bandwidth for users on a random basis as required by traffic demands, was incompatible with the three other spread-spectrum proposals. [Ref. 69:pp. 655-656]

Public comments and FCC views supported a competitive RDSS:

Potential RDSS users state that competition will provide constraints on pricing and ensure continued innovation. All applicants state that multiple entry is possible, although Omninet urges that this policy should not be pursued at the cost of adopting a less efficient system design. While technical efficiency is a desirable goal, we have found that the benefits of competition, including continued innovation,

> will be best provided by independently licensed multiple systems. A design permitting only one system to would have to be unquestionably superior to justify a departure from this policy. [Ref. 69:pp. 653-654]

The FCC determined that Omninet's proposal was a hybrid MSS-RDSS system which was very similar to Omninet's then-pending MSS application. The Commission decided that Omninet's proposal was not superior to the system submitted by the other applicants and that the competitive benefits provided by independently licensed RDSS systems were not outweighed by Omninet's design, which would not have permitted multiple entry. [Ref. 69:p. 660] On 22 April 1986, the Commission authorized the spread-spectrum system proposed by the other three applicants and adopted only the minimum RDSS technical standards, leaving it to the licensees to work out the necessary sharing criteria. Omninet was afforded an opportunity to amend its proposal to conform with the adopted technical requirements [Ref. 69:p. 662]. RDSS licenses were ultimately granted to all four petitioners. Provisions were made to allow other qualified companies to apply for RDSS licenses. Firm project milestones were also set:

> All licensees are required to begin construction of at least the first satellite of the system within one year of grant of the construction permit, and must begin construction of the remaining satellites within two years of grant. Construction of the first satellite must be completed within four years of grant. Full systems must be launched and operational within six years of grant....Failure to fulfill these conditions will render the authorization null and void. [Ref. 69:p. 665]

Following the ruling, MCCA joined with Geostar. The other licensees eventually dropped their RDSS efforts.

2. Regulation

The FCC observed that in providing radiolocation, the content of the communications remains under the licensee's control and thus is not a common-carrier service. Applicants and other commenters asserted that RDSS offerings must be permitted to be tailored to meet the needs of individual customers and that common-carrier obligations would impede this ability. Based on these points the Commission ruled that it would not impose common-carrier regulation on RDSS license holders [Ref. 69:pp. 665-666].

E. FCC RULINGS ON MSS

1. Frequency Allocation

The National Aeronautics and Space Administration (NASA) began work on the concept of a mobile satellite in the late 1970's. Numerous design and marketing studies showed that the concept would be technically and economically feasible. In November 1982 NASA filed a petition with the FCC to authorize MSS and establish a frequency allocation. In response to this petition, the FCC adopted a NPRM on 21 November 1984 proposing the establishment of a new Mobile Satellite Service. In this notice the FCC concluded that it was in the public interest to propose an allocation in the 800-900 MHz UHF land mobile reserve frequency bands, and that

approximately 20 MHz of spectrum would be required to accommodate the MSS in the long term. Faced with competing requirements for terrestrial use of the UHF land-mobile band, the Commission proposed a two-part allocation for MSS. Eight MHz of the UHF spectrum was planned to be allocated along with additional L-band spectrum assigned to the Aeronautical Mobile Satellite (AMSS) which was not required for that service. The FCC envisioned that a "hybrid" MSS satellite could be developed capable of combined operation on both the UHF and L-band frequencies. The FCC also invited applications for this service to be filed by a specified cut-off date. [Ref. 70:p. 1841]

Public comment indicated that MSS would be a desirable and worthwhile service. While there was general support for MSS, there was strong disagreement over whether the UHF frequencies should be allocated. Land-mobile advocates asserted that the public interest would be better served by allocating UHF spectrum for terrestrial land-mobile purposes. MSS proponents generally supported the proposed hybrid frequency allocation and argued against an allocation only in the L-band. Stated requirements for UHF band allocation included the technical and economic advantages of UHF, compatibility with cellular-radio systems, and compatibility with Canada's planned MSS system. Aviation interests generally opposed the allocation of any of the L-band Aviation Mobile Satellite spectrum. [Ref. 70:pp. 1841-1844]

The FCC found there was no reason why MSS could not technically or economically operate entirely on the L-band. The Commission agreed with the National Telecommunications and Information Administration (NTIA) comments that it was unlikely that the AMSS would require the entire L-band allocation on an exclusive basis. The marginal cost increases for an L-band terminal were judged not substantial enough to present a significant barrier to initiation of the service. The Commission also determined that cellular radio and MSS technologies were not adequately similar enough to enable the production of a "combined" terminal which would have much of a cost or performance advantage over two separate transceivers. The FCC noted that the issue of shared development costs and back-up capability with the Canadian MSS could occur at L-band as well as at UHF. However, the Commission stated that based on the principal of mutual comity, it would consider a possible joint Canadian/U.S. MSS system using four MHz of UHF spectrum placed in reserve as an adjunct to an L-band MSS system [Ref. 70:pp. 1843-1844]. The Commission stressed that the four MHz of spectrum would not be held indefinitely in reserve and that this spectrum would be reallocated for domestic use if a timely agreement with the Canadians was not reached [Ref. 70:p. 1845].

On 24 July 1986, the FCC allocated two 13.5 MHz segments of L-band spectrum (1545.0-1558.5 MHz and 1646.5-1660.0 MHz) for the Mobile Satellite Service and the

Aeronautical Mobile Satellite Service, Route (AMSS(R)). AMSS(R) communications are related to aeronautical safety, navigation, air traffic control, and surveillance. Two four and a half MHz segments at 1545-1549.5 MHz and 1646.5-1651.0 MHz were to remain as allocated for AMSS(R) on a primary basis, with MSS permitted on a secondary basis. The remaining nine MHz of each L-band segment would be shared by AMSS(R) and MSS, with AMSS(R) having priority access. U.S. frequency allocations are shown in Figure 88 [Ref. 71:pp. 8-9].

2. Establishment and Licensing of a MSS Consortium

In response to the Commission's November 1984 notice of proposed rule making, 12 companies filed applications proposing MSS systems. Extensive pleadings concerning these applications were also filed. A fundamental issue raised by the amount of spectrum allocated for the MSS was the number of firms which could be licensed to provide the service. In its NPRM the Commission stated that because of economical and technical constraints it was unlikely that any more than one entity would be licensed.

None of the systems proposed by the applicants was capable of sharing the allocated frequencies with another system. The FCC determined that it was not in the best interest of the MSS to license separate frequencies to multiple firms. A larger total bandwidth would allow a greater variety of services to be provided by the MSS system, with a corresponding increase in the customer base. The

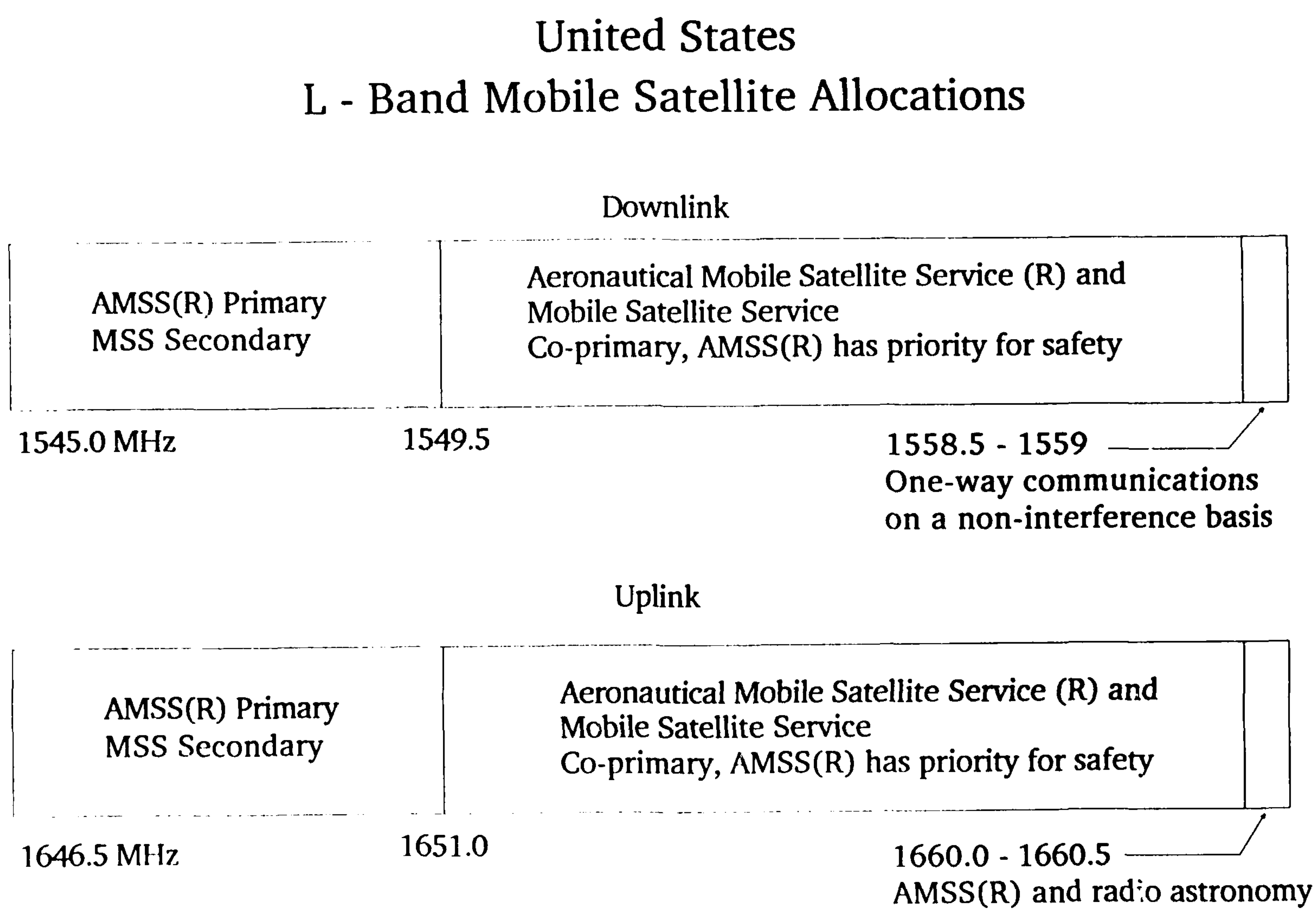

Figure 88. United States L-Band Mobile Satellite Allocations

majority of the applicants stressed that a MSS system would have to be used to the widest possible extent if the cost of the system was to be recovered and a reasonable profit earned. Applicant cost estimates for an MSS system ranged from $50 million to $600 million, with the FCC estimating a minimum of $300 million [Ref. 72:p. 492].

Because of the requirement for a full allocation of bandwidth, the substantial system costs and to facilitate coordination with other users of the spectrum (including Canada), the Commission concluded that the public interest would best be served by the formation of a consortium. In arriving at the decision to use a consortium, the FCC evaluated and rejected other licensing alternatives such as a lottery, an auction, and comparative hearings:

> Having evaluated the proposed alternatives for awarding an MSS license, we conclude that a consortium will be more efficient, less costly and more apt to meet our goals than any other alternative. A consortium will permit mobile satellite services to be made available expeditiously. It also will permit broad participation from all interested and able applicants, which, in turn, will have a positive effect on the shape of this new industry. In order to allow all entities who have demonstrated an interest in MSS a chance to participate, we will develop a multiple ownership arrangement that will provide these applicants with this opportunity. [Ref. 72:p. 488]

The Commission required each applicant to deposit an initial cash contribution of $5 million into the consortium, with subsequent ownership interests proportional to the capital and non-capital contributions of each participant [Ref. 72:p. 488].

The FCC did not approve any particular system design:

> Although the ultimate MSS system design is subject to Commission approval, we believe that the consortium itself, and not the Commission, is best qualified to specify the initial system design striking the balance among cost, efficiency, and the allocation requirements to provide the public with the best service at the lowest cost. We encourage the consortium to use state-of-the-art technology to the extent that it is affordable, keeping in mind that less efficient satellites will only serve to inhibit the availability of mobile satellite services. [Ref. 72:p. 489]

Of the 12 applicants, one dropped out, and three did not meet the financial qualifications. The remaining eight applicants formed the American Mobile Satellite Corporation (AMSC) and filed an amended technical proposal for the MSS system and a joint operating agreement. [Ref. 13]

In December 1987, certain aviation interests filed a petition requesting the Commission conform the U.S. frequency allocations for AMSS(R) and LMSS in the L-Band to those adopted at the 1987 Mobile WARC (discussed below). On 31 May 1989, the Commission denied this petition, stating that full consideration was given to the needs of the aeronautical safety services in the earlier MSS allocation decisions, and that its allocation actually provided a greater amount of spectrum for AMSS(R) than did the international allocation, as well as providing more primary spectrum for MSS. The FCC also noted that the U.S. allocation would encourage investment in a MSS system that would better serve both AMSS(R) and MSS. [Ref. 71:pp. 7-8, 20]

Also on May 31, 1989 the Commission authorized AMSC to construct, launch, and operate the first generation domestic mobile-satellite system and to provide the full range of land, aeronautical and maritime mobile satellite services, including:

a. mobile telephone service (MTS)--voice communications interconnecting mobile land vehicles, boats or aircraft and the public switched telephone network;

b. mobile radio service (MRS)--a two-way voice dispatch service between a user terminal and a base station;

c. mobile data service (MDS)--two-way data communications that may be combined with MTS or MRS;

d. aeronautical service--voice and data communications for safety and other purposes including

   (1) air traffic control (ATC)--communications related to safety and regularity of flight,

   (2) aircraft operational communications (AOC)--flight management communications between the aircraft and ground facilities,

   (3) airline administrative communications (AAC)--communications to improve airline customer services,

   (4) airline passenger communications (APC)--commercial voice and data passenger communications;

e. transportable service--telephone and two-way data communications to users in sparsely populated areas using portable terminals at fixed locations; and

f. paging service--one-way communications on a non-interference basis.... [Ref. 71:pp. 19]

Voice and data services will be capable of using a variety of digital modulation formats.

3. Regulatory Issues

The FCC concluded that because only one MSS license was to be granted, the space segment operator was under obligation to serve the public on a nondiscriminatory basis. As a result, the FCC would regulate the consortium as a common carrier. However, because there are some partial substitutes for MSS services, such as cellular and other radio systems in more populated areas, and RDSS for vehicle fleet monitoring and communications, the Commission decided to classify the consortium as a nondominant carrier. This classification allows streamlined tariff-filing and facilities-authorizations procedures.

Based on the Commission's requirement that the MSS system be openly accessed through multiple earth stations, ground-segment licensees will be unregulated. Many entities, through their own gateway stations, would be able to offer the MSS service to their own customers in competition with other resellers. In this competitive environment gateway stations would not be able to charge unreasonable or discriminatory prices. The Commission also stated that they would not regulate service providers of individual units for the same reasons [Ref. 72:p. 490].

The FCC decided to preempt state regulation over technical standards, entry and rate regulation of the space segment. The Commission stated that they would not preempt state regulation of intrastate common carrier services

associated with the ground segment of the system. [Ref. 72:p. 491]

F. TREATMENT OF RDSS AND MSS AT THE WORLD ADMINISTRATIVE RADIO CONFERENCE FOR THE MOBILE SERVICES (WARC MOB-87)

Although the FCC had authorized RDSS and MSS prior to 1987, these services and frequency assignments were not consistent with the International Telecommunication Union (ITU) allocations. Fortunately, the mobile WARC was held in Geneva from 14 September 1987 to 17 October 1987. The purpose of this conference was to review and revise the ITU mobile service radio regulations.

The U.S. had four main conference objectives. Two of these were apportioning sufficient spectrum to permit the establishment of RDSS and allocating sufficient worldwide frequencies to ensure the economic viability of the MSS. [Ref. 73:p. 1]

The radio regulations of the International Frequency Registration Board (a part of the ITU) not only give specific frequency allocations for particular communication routes, but also they also take into account the class of traffic. Prior to the WARC, all aeronautical communications via satellite was described as Aeronautical Mobile Satellite Service, Route or AMSS(R). By definition, these are communications related to the safety and regularity of flight, and were accorded primary use of assigned frequencies. The U.S. proposed that the L-band frequency ranges allocated exclusively to AMSS(R) be

reduced, and that LMSS be given co-primary allocation along with AMSS(R) on 19 MHz of uplink and downlink frequencies. The U.S. argued that computerized equipment already in use for allocating frequencies was capable of automatically giving aeronautical communications priority over other users, and this would enable the most socially beneficial use of limited spectrum. The U.S. also wanted to establish, at least in the Americas, a general mobile-satellite service allocation, for use by any kind of mobile user [Ref. 74]. As shown in Figures 89 and 90, the U.S. proposals would change the classification of several sections of the L-band.

The executive summary of the U.S. delegation's report provided the following synopsis:

1. RDSS

> We achieved our two major RDSS objectives, of obtaining allocations for RDSS sufficient to permit the service to begin operating initially in North America, with possibilities of orderly expansion globally, and ensuring a status in the Radio Regulations for RDSS which will result in international recognition and protection. [Ref. 73:p. 3-4]

2. MSS

> We were successful in establishing the principle of world-wide MSS allocations, but we did not achieve all the spectrum we would have liked. However, given the widespread opposition to accepting such an innovative concept, we believe the achievements of the conference were significant. [Ref. 73:pp. 4-5]

Both RDSS and MSS were controversial. While many nations supported a primary allocation for RDSS, opposition came from Cuba, the Eastern bloc countries led by the USSR,

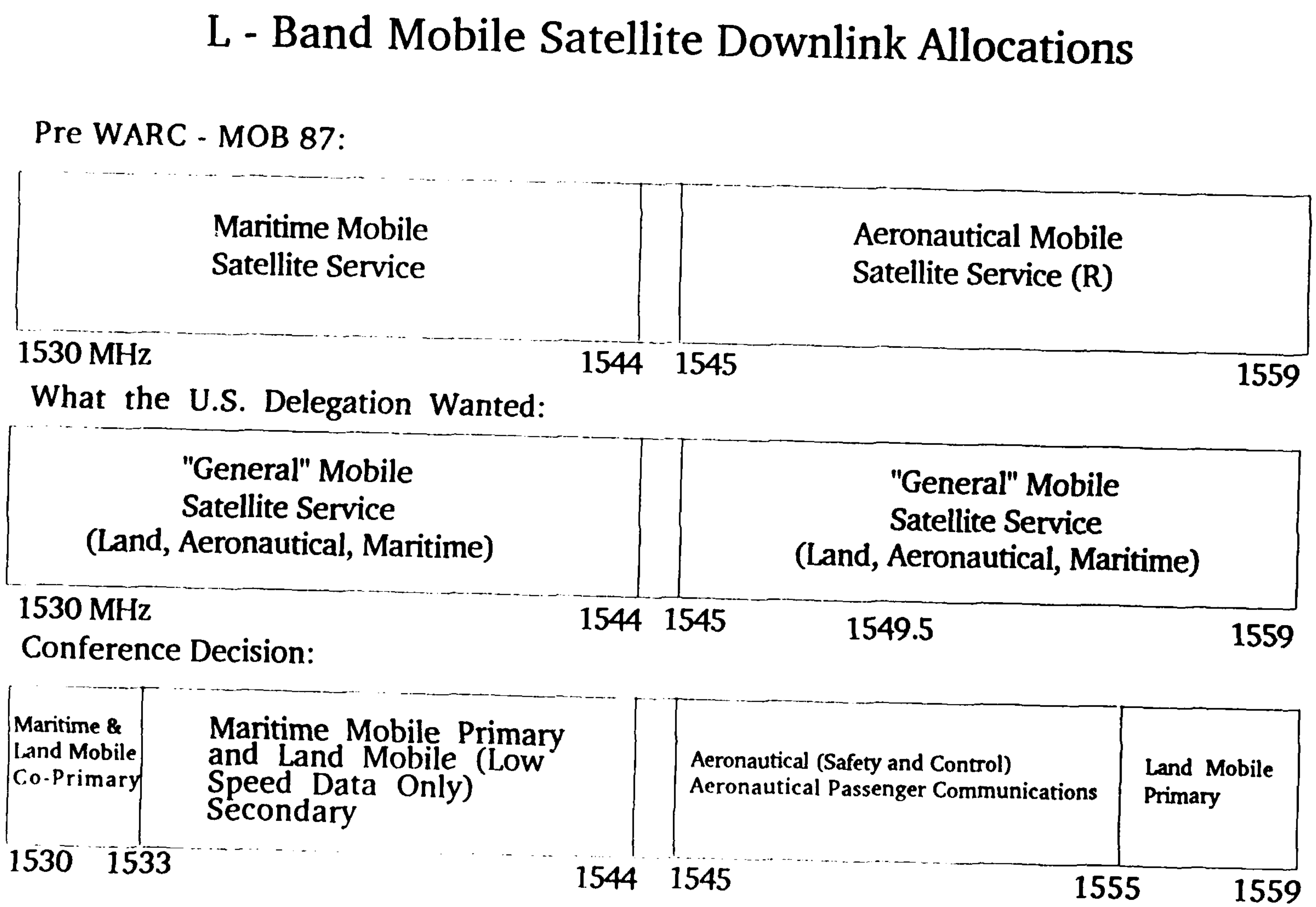

Figure 89. L-Band Mobile Satellite Downlink Allocations

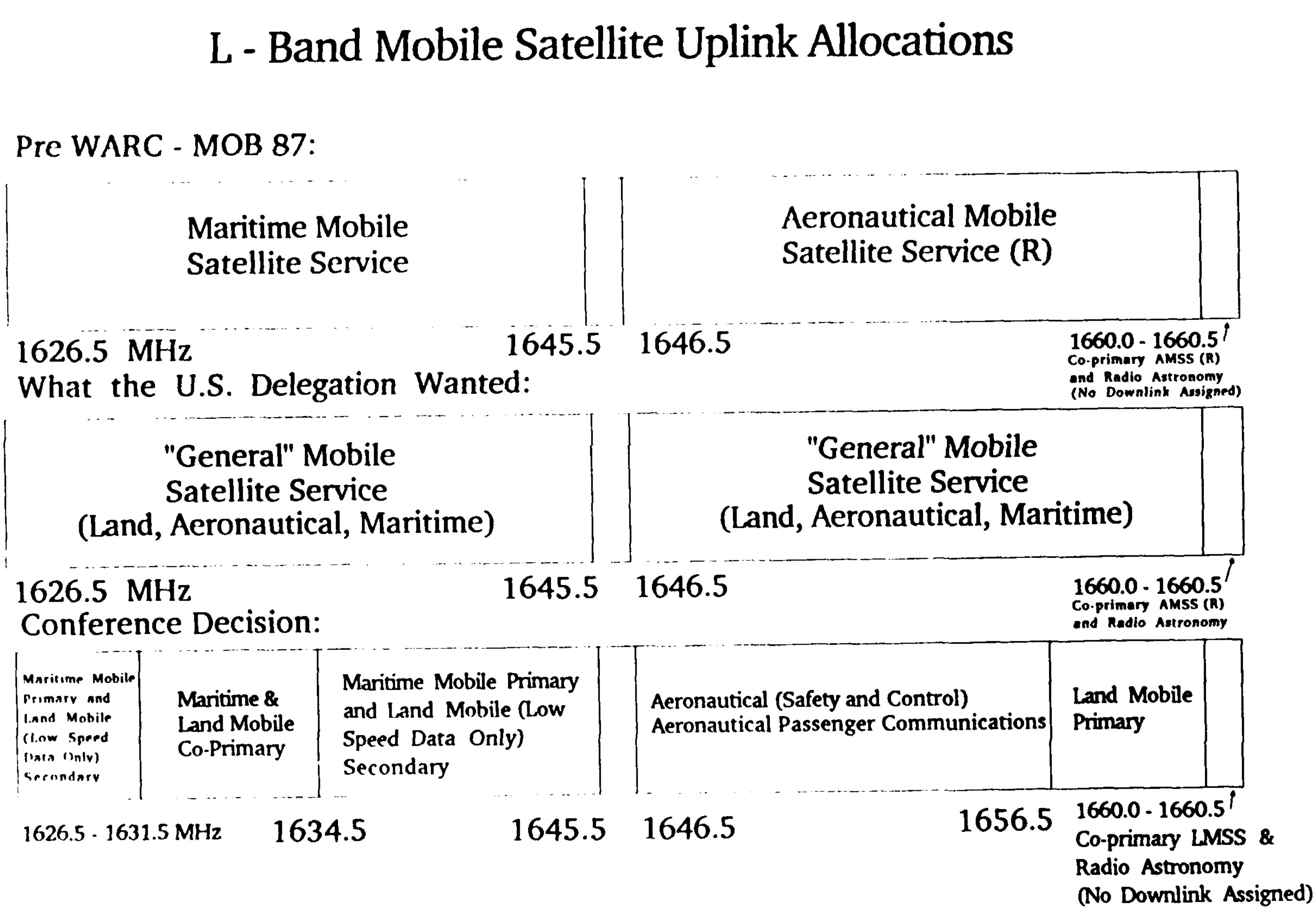

Figure 90. L-Band Mobile Satellite Uplink Allocations

and the European Conference of Postal and Telecommunications Administrations (CEPT), particularly the United Kingdom, Sweden, the Federal Republic of Germany, and Switzerland. Opposition to RDSS was centered on the protection of the existing terrestrial services, and doubts were raised about costs and benefits to developing countries. [Ref. 73:pp. 14-16]

> After extensive formal debates and informal coordination, it was apparent that no uniform worldwide allocation would be achieved. The allocations that finally emerged were the same as the United States domestic table at 1610-1626.5 and 2483.5-2500 MHz, but not at 5117-5183 MHz for the RDSS transfer links, which were set at 5150-5216 MHz. The allocations in the Western Hemisphere will be on a primary basis, and in Europe/Africa and Asia, on a secondary basis. Primary RDSS allocations in specific countries were included in footnotes, subject to coordination agreement with other countries. Various other footnotes excluded RDSS from the safety provisions, provided protection for existing services, and provided for alternative allocations or different categories of service on a national basis. Finally, various technical and regulatory provisions were incorporated into the Radio Regulations which will permit the new service to move forward. Studies, however, should continue, looking towards a future conference to upgrade the allocations in the other regions of the world.... [Ref. 73:pp. 16-17]

The Mobile Satellite Service was treated less kindly:

> The United States and Mexico had proposed that the spectrum currently allocated to the Maritime Mobile Satellite Service and Aeronautical Mobile Satellite (Route) Service be reallocated to a more general mobile satellite service (land, aeronautical, and maritime). Canada made a similar proposal....
>
> Five other MSS proposals were introduced....In working group and full committee discussions, opposition came from the Europeans, who had adopted the International Civil Aviation Organization (ICAO) recommendation that the aeronautical spectrum not be reduced....Brazil, France, and the USSR also opposed for reasons related to other systems.

> Eventually, guidelines were adopted, providing the basis for a compromise....
>
> The resulting allocations, associated regulatory provisions and accompanying resolutions...were not agreed upon until some eight hours after the Conference was scheduled to complete its work. Because of the late hour, the Conference was in a take-it-or-leave-it mood. In an effort to gain additional spectrum for the mobile satellite service, Canada, the United States, and Mexico proposed a secondary footnote restricting use within national boundaries. Our proposal was defeated by secret vote in the Plenary. [Ref. 72:pp. 16-17]
>
> Since these allocations are less than the U.S. sought, and because of the potential coordination difficulties, the United States reserved its options, while recognizing the priority of Aeronautical Mobile Satellite (Route) Service and maritime safety communications, by reserving the right to use the 1530-1559 and 1626.5-1660.5 MHz bands in the way most appropriate to satisfy its Mobile Satellite Service requirements. [Ref. 72:p. 3]

In other words, the conference was put on notice that Canada and the U.S. did not agree with the WARC international MSS allocations, and that they would allocate the L-Band spectrum in a manner which best served their domestic requirements.

RDSS and MSS user terminal frequencies allocated by the mobile WARC are shown in Figures 89 to 91 [Ref. 75]. The WARC MOB-87 resolved to bring up the issues of RDSS and MSS frequency allocations and equipment at it next session to be held in 1992. [Ref. 67:p. 140]

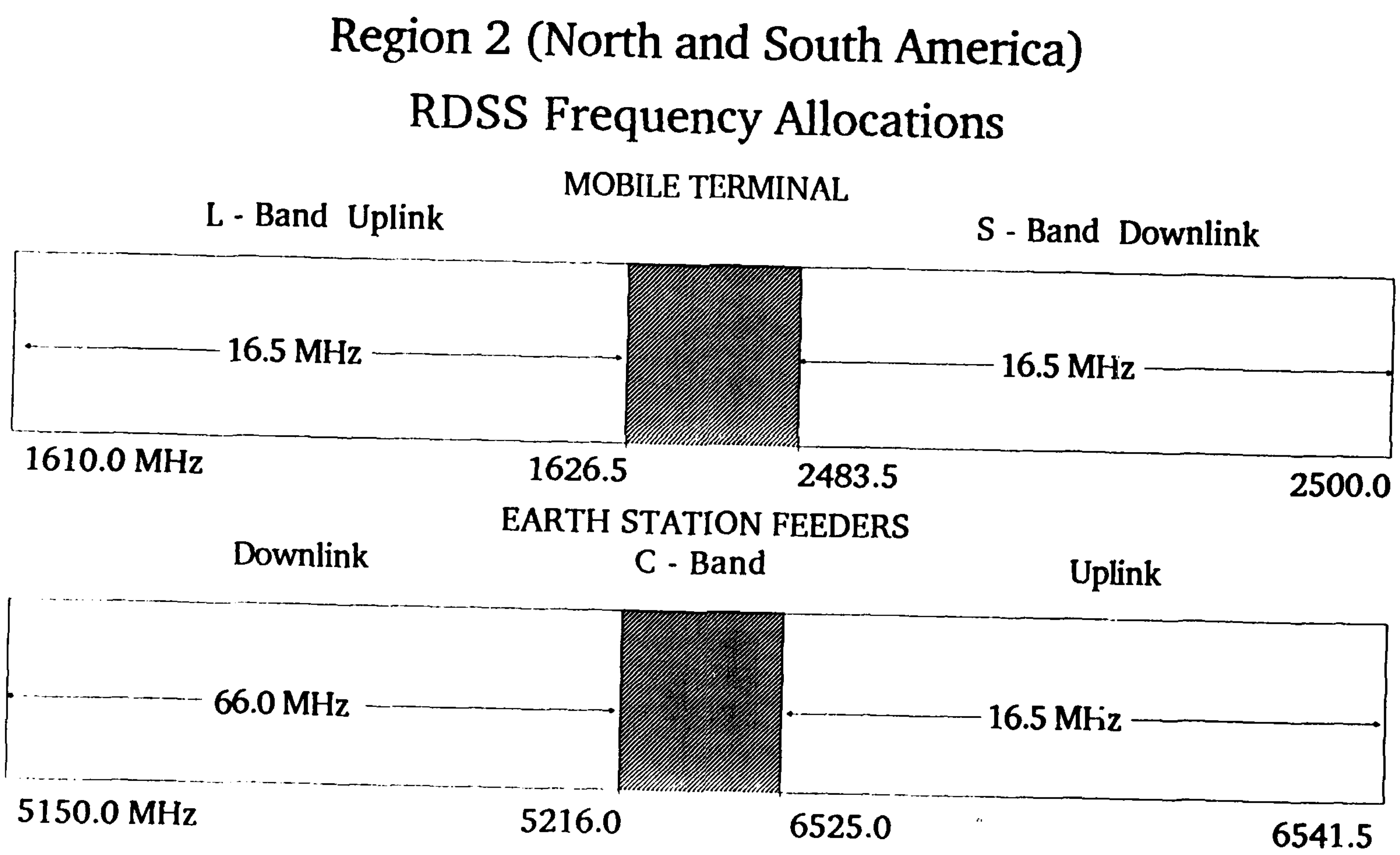

Figure 91. Region 2 (North and South America) RDSS Frequency Allocations

G. APPLICATIONS TO USE FIXED SATELLITE SERVICE TRANSPONDERS FOR MOBILE SATELLITE USE

1. Qualcomm Application to Operate a Network of Ku-Band Mobile Terminals

Qualcomm's application to operate a network of 20,600 mobile and transportable very small aperture satellite terminals (VSAT) was placed on public notice in January 1988. Qualcomm proposed providing mobile-satellite communications service using the 12/14 Ghz Ku-band, and requested a blanket authorization for these stations under the VSAT order.

a. Service Justification

Qualcomm proposed to use two transponders on the GTE Spacenet GSTAR 1 satellite. Qualcomm asserted that because its system would use existing satellite capacity, it would be able to bring the benefits of two-way satellite-based mobile communications, including ancillary position location information, to the public immediately.

b. Spectrum Allocation

The 14.0-14.5 GHz Ku-band uplink is allocated both domestically and internationally to the land mobile-satellite service (LMSS) on a secondary basis. The 11.7-12.2 GHz downlink contains no provision for LMSS service. Both frequency bands are allocated to the fixed satellite service on a primary basis. Qualcomm argued that a companion secondary downlink allocation to the 14.0-14.5 GHz uplink was not necessary because the satellite can not distinguish between moving and stationary terminals. Qualcomm also

maintained that as long as the mobile operations conform to the technical standards for the fixed service, fixed-satellite users would not suffer unacceptable interference.

c. Commission Ruling

The FCC concluded the public interest would be served by granting Qualcomm's application. Because the table of frequency allocations provided no allocation for a mobile-satellite downlink at 11.7-12.2 GHz, the commission ruled the service could only be provided on a non-interfering basis to all other services, both primary and secondary. The land-mobile operator is also required to accept any interference from primary or secondary users. Technical and operating standards were specified to minimize the possibility of any interference. Qualcomm was issued a blanket VSAT authorization for its terminals on January 27, 1989. [Ref. 7]

2. Geostar Application to Use a C-Band Interim Downlink

On 8 May 1989, the Commission granted Geostar a blanket license for 20,000 C-band receive-only RDSS units. This was in response to Geostar's request to expand its interim service to provide two-way communications capability.

The requested downlink frequency range of 3.7-4.2 GHz is allocated to the fixed-satellite service and the fixed-terrestrial service on a shared basis. Geostar stated that their downlink transmissions would have characteristics similar to a video signal and would cause no more interference than other FM-TV carriers used in the fixed-satellite service.

The Commission concluded that the public interest would be served by allowing Geostar to operate on an interim basis in the C-band, providing that the downlink transmissions not interfere with other authorized users of the band, and that RDSS users must accept any interference from other satellite and terrestrial services. [Ref. 6]

H. PROPOSAL FOR A DIGITAL LAND MOBILE MESSAGING SERVICE

In June 1988, Geostar Messaging Corporation (GMC), a wholly-owned subsidiary of Geostar Corporation, submitted to the FCC a proposal for a new Digital Land Mobile Messaging Service (DLMSS) [Ref. 58]. This service would use low bit rate (up to 4800 bps) digital communication for the transmission of voice and data.

1. Service Justification

GMC's application was based primarily on the assertion that RDSS and LMSS will be unable to fully meet future mobile communication needs. Under this proposal:

> The DLMSS will serve markets different from, but related to, those already served by terrestrial land mobile services. It also addresses requirements different from, but similar to, those that are being served by radiodetermination satellites or will be served by the voice-oriented land mobile-satellite system when implemented. In addition to meeting specialized market needs, the DLMSS will promote improved competition among the various mobile-satellite services. [Ref. 58:p. 3]

> ...existing and proposed satellite systems are not optimized to serve the needs of land mobile users for low-speed data communications. For example, the proposed AMSC system is designed primarily for voice, rather than digital data communications. Indeed, AMSC's application is the product of a lengthy proceeding whose major purpose was to provide

telephony to remote and mobile users. The AMSC five KHz analog channel design is, in fact optimized for toll quality voice services.

...RDSS, while a digital service, is not designed to support messages of substantial length...RDSS employs spread-spectrum technology, which efficiently allows millions of users to share a common channel to obtain accurate position fixes and to transmit brief bursts of data. That technology, while superior for positioning, is not well-suited for sustained data communications. [Ref. 58:p. 8]

2. Spectrum Allocation

As illustrated in Figures 89 and 90, the 1987 Mobile WARC revised the L-band allocation for the Maritime Mobile Satellite Service (MMSS) to permit certain Land Mobile Satellite Services on a shared basis. GMC requested the FCC modify its Table of Allocations to provide domestic co-primary allocation for DLMSS in the 1530-1544 MHz (Earth-to-Space) and 1626.5-1645.5 MHz (Space-to-Earth) bands to be shared with the MMSS. [Ref. 58:p. 15]

GMC believes that co-primary status is important to the development of the DLMSS. Such status would improve the attractiveness of DLMSS in obtaining risk capital and would better secure its status in coordination. The commission has previously acknowledged that such status is critical for the development of new services. [Ref. 58:pp. 18-19]

GMC also proposed that operations in the co-primary DLMSS spectrum be restricted to digital transmissions.

3. Interference Prevention

The principal user of Maritime Mobile Satellite Service (MMSS) frequencies is the International Maritime Satellite Organization (INMARSAT). For an early-entry "add-on" satellite package, GMC proposed interference coordination

with INMARSAT by ensuring the same frequencies are not used in the same geographical area [Ref. 58:pp. 22-24]. GMC also proposed the eventual use of dedicated DLMSS satellites and bi-directional transmissions. Under this arrangement, DLMSS user frequencies would be reversed, with land mobile equipment transmitting in the maritime downlink band and receiving in the uplink band. GMC stated this would almost double the amount of users which could be supported within the jointly allocated spectrum, would minimize interference in the open ocean and inland areas, and could be implemented in costal regions through careful channelization and other techniques [Ref. 58:pp. 24-25]. Figure 95 in Appendix A illustrates the earth coverage areas provided by INMARSAT satellites.

4. Licensing Policies

GMC recommended the FCC process applications to provide DLMS service concurrently with the rulemaking, similar to how RDSS was handled. Should it be approved, this would enable faster implementation of the service. In the event that multiple applications for DLMSS are received, GMC favored creation of a consortium, similar to that of AMSC. This approach would avoid the delays of comparative hearings. [Ref. 58:pp. 27-29]

GMC also recommended that the DLMSS be classified as a non-dominant common carrier service:

> As the market for data communications and for mobile services are both highly competitive wherein no party will have market power, the Commission should regulate licensees

of the space segment in the DLMSS as non-dominant carriers using streamlined regulation. [Ref. 58:p. 30]

5. Commission Ruling

The Commission denied GMC's petition on 8 February 1990, stating:

> ...GMC had initially proposed a long-term system that would employ reverse band transmissions. Several commenters expressed serious technical concerns with respect to this aspect of GMC's proposed system. We believe that allowing reverse band operation in the mobile satellite services at this time is infeasible. Because of severe mobile-to-mobile interference, reverse band operation would restrict MSS mobile terminals to operation in areas outside of these in which INMARSAT Standard-C and aeronautical terminals operate. As a practical matter, it would be nearly impossible to prevent MSS mobiles from operating within these restricted areas. In addition, reverse band operation would require that existing MMSS system operators invest in additional hardware and software to make this type of sharing workable. Because of the interference potential between systems and the additional burdens that would be imposed on the existing operator in the MMSS spectrum, reverse band operation will not be permitted. [Ref. 57:p. 4]

I. FCC PROPOSAL TO ALLOCATE ADDITIONAL L-BAND SPECTRUM FOR A GENERIC MOBILE SATELLITE SERVICE

Partly in response to GMC's petition to establish a Digital Land Mobile Satellite service, the FCC on 8 February 1990 adopted a Notice of Proposed Rule Making to allocate an additional 33 MHz of L-band spectrum for generic mobile satellite service [Ref. 57]. The U.S. Table of Frequency Allocations would be expanded to allow mobile satellite operations over a wider frequency range:

> Based on our review of the information submitted in response to GMC's petition and our assessment of U.S. mobile communication needs in light of the 1987 Mobile WARC, we are

proposing to allocate the frequency bands 1530-1544 MHz and 1626.5-1645.5 for use by the mobile satellite service....

We believe that the provision of MSS in this band could lead to more efficient orbit and spectrum utilization. In particular, any spectrum that becomes available domestically may be used to offer satellite service providers the opportunity to provide the public with new and unique services. In addition, in the future the Commission may also consider whether such spectrum might be necessary to help satisfy the spectrum requirements of authorized services, such as MSS, that may require additional spectrum as a result of the international coordination process. In developing this proposal, we note that the 1987 Mobile WARC, in providing for the operation of LMSS services in this band, recognized that maritime services may not require all 33 MHz of this spectrum and that sharing between MMSS and other services may be possible. We believe that our proposal for a generic MSS rather than the more limited LMSS allocation adopted at the 1987 Mobile WARC or the DLMSS allocation suggested by GMC has a number of benefits. First, a generic MSS allocation will provide flexibility to new satellite service providers in developing systems to meet the needs of all mobile users. In addition, a generic MSS allocation in this band would be consistent with our treatment of the related, adjacent bands...which the 1987 Mobile WARC allocated for AMSS(R) and LMSS, respectively.

...the 1987 Mobile WARC allocated the 1530-1533 MHz (space-to-Earth transmission) and 1631.5-1634.5 MHz (Earth-to-space transmission) bands for shared use by LMSS and MMSS on a co-primary basis. Our proposal to allocate the six MHz of spectrum in these bands generically for MSS (i.e., MMSS, LMSS, and AMSS), which will also permit AMSS operations within these bands, generally comports with the international allocation adopted at the 1987 Mobile WARC. The bands 1533-1544 MHz (space-to-Earth transmission), and 1626.5-1631.5 MHz (Earth-to-space transmission), were allocated at the 1987 Mobile WARC for primary use by MMSS and secondary use by LMSS. Further, the secondary LMSS allocation was restricted to non-speech, low bit-rate data communications. Our proposal for a generic MSS allocation would permit equal use by the MMSS, AMSS, and LMSS. As noted above, ITU Radio Regulation No. 342 permits administrations to allocate spectrum for nonconforming uses so long as the nonconforming use does not cause harmful interference to the *conforming* uses as established in the ITU Radio Regulations. We believe that a nonconforming, generic MSS allocation would be in the public interest and that conforming and nonconforming uses can be accommodated with

the appropriate international coordination. [Ref. 57:pp. 3-4]

The Commission went on to state:

> We recognize that adequate spectrum must be available in these bands for important maritime-safety related services such as the Global Maritime Distress and Safety System (GMDSS), and that these services must be protected from harmful interference....To implement this policy we propose to add a new footnote...to the Table of Frequency Allocations that would provide MMSS distress and safety communications with real-time, priority preemptive access throughout the subject bands...any system operating in these bands would be required to be coordinated internationally with the INMARSAT system...currently the only satellite communications system capable of meeting the global coverage requirements of the GMDSS. [Ref. 57:p. 4]

Thus, in a manner somewhat similar to the U.S. response to the 1987 Mobile WARC MSS allocations, the Commission has proposed using these frequency bands in a manner which most suits domestic U.S. interests. Allocation of the frequencies in this manner will give greater flexibility to U.S. mobile satellite-system operators, while ensuring that international safety services are not jeopardized.

J. INTERNATIONAL MARITIME SATELLITE ORGANIZATION (INMARSAT)

1. Background

INMARSAT is a nonprofit multinational organization which was originally conceived to provide maritime mobile-satellite services. INMARSAT has expanded its coverage to include aeronautical and land mobile-satellite services. Information on INMARSAT's organization structure and Standard-C service is provided in Appendix A.

2. FCC Policy for Provision of INMARSAT Aeronautical Services in the U.S.

On 31 May, 1989 the FCC authorized the Communications Satellite Corporation (COMSAT) to provide INMARSAT aeronautical satellite services in the U.S. COMSAT is the U.S. Signatory for the provision of maritime services via INMARSAT. The Commission limited COMSAT's ability to provide aeronautical service to international flights. The American Mobile Satellite Consortium (AMSC) will provide domestic aeronautical satellite services.

Before this ruling, the Commission requested comments on the creation of a consortium to serve as the U.S. Signatory to INMARSAT for the provision of aeronautical services. The FCC subsequently rejected this approach because of a lack of clear private-sector commitment and other factors which would complicate and delay implementing the service.

> The Commission said it would authorize the U.S. Signatory, COMSAT, to provide INMARSAT aeronautical services as ancillary to its provision of maritime services. Under this policy, access to the INMARSAT aeronautical space segment by other U.S. service providers will be through COMSAT. COMSAT's space segment services and rates will be subject to the competitive pressures of other INMARSAT Signatories and the U.S. domestic mobile satellite system authorized to AMSC. The AMSC system will have a certain range of effective coverage beyond U.S. borders and thus will be able to compete with INMARSAT for some international aeronautical mobile satellite traffic.
>
> The Commission said this approach was the best means of promoting competition in the provision of INMARSAT aeronautical services to end users while achieving timely and effective U.S. entry into a world market.... [Ref. 76]

3. Use of INMARSAT Within the U.S. For Land Mobile Satellite Services

As discussed in Appendix A, INMARSAT's charter has been changed to authorize land mobile-satellite services. However, operation within geographical boundaries of a country will require permission of the appropriate regulatory body.

FCC personnel stated it is unlikely that INMARSAT will be given a blanket authorization to provide land mobile services within the U.S. This is because three domestic firms (Geostar, AMSC, and Qualcomm) are already authorized to provide mobile satellite-type services. The ability to select from three U.S. firms provides a degree of price and service competition, and it is not desired that revenues from entirely domestic communications be channeled into an international consortium.[1]

K. PETITION BY ORBITAL SCIENCES CORPORATION TO ESTABLISH A MOBILE DATA SERVICE USING LOW-EARTH ORBIT SATELLITES

1. Background

On 28 February 1990, the Orbital Communications Corporation (ORBCOMM) petitioned the FCC to initiate a rulemaking to permit a mobile data and position service using a constellation of 20 low-earth orbiting satellites. ORBCOMM also requested a waiver to proceed immediately with the design and development phases of the satellites to be used in its

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[1]Telephone conversation between Mr. Joel Pearlman, FCC, and the author, April 1989.

proposed low-earth orbit system [Ref. 77]. ORBCOMM's system proposal is discussed in Appendix A.

Communications between the ORBCOMM satellites and earth stations is planned to take place in the VHF and UHF bands using a total of 898 KHz of bandwidth. The requested VHF spectrum is used primarily by the government and military services, while the UHF frequency is unoccupied. Operation at these frequencies allows conventional and high production volume components to be used in the assembly of inexpensive mobile terminals. Additionally, the 970 Km (600 mile) satellite orbits require substantially less power and antenna gain for communications than do geostationary satellite systems. As a result, ORBCOMM expects that mass-produced basic communication terminals will be sold at retail for around $50, and a combination communications/position determination terminal will retail for about $150 [Ref. 77:pp. 5-6]. ORBCOMM's forecast terminal prices and monthly fees are substantially less than those charged by geostationary mobile-satellite systems. ORBCOMM projects that its system is capable of serving between 10 and 20 million U.S. users, of which over 85% will be for emergency types of services. GPS time signals and doppler positioning will be offered free of charge to any user. Other non-voice short message services which would be provided are similar to those offered by geostationary systems [Ref. 77:p. 22].

2. Foreign Trade Benefits

In addition to meeting domestic U.S. needs, ORBCOMM cited the benefits that would accrue from providing worldwide services:

> The Commission is well aware of the negative trade balance the United States has developed for telecommunications goods and services. The ORBCOMM system can produce significant trade benefits for the United States to help offset the current telecommunications trade deficit. Although designed (and financially justified) as a U.S. domestic service, one major advantage of operating in low-earth orbit is the global coverage provided by the satellite constellation--capacity that can be tapped throughout the world with only minimal, incremental investment in ground stations and with complete reuse of the space segment.
>
> If the United States is the first nation to deploy such a low-earth orbiting system, than it will be well positioned to "export" this service to other countries, since the capability is inherent in the non-geostationary system. Indeed, ORBCOMM estimates that revenues and licensing fees from foreign use of the ORBCOMM system could exceed $650 million over the life of the satellites. Moreover, given the leadtime U.S. manufacturers would have over foreign producers, ORBCOMM estimates that some $200 million in telecommunications equipment for foreign gateways would be exported by U.S. manufacturers. In addition, assuming a strong domestic manufacturing base is established as a result of the U.S. lead, then subscriber equipment exports could exceed several hundred million dollars. [Ref. 77:pp. 16-17]
>
> ...the Commission can help secure global availability of ORBCOMM service (and the attendant benefits) by seeking to ensure that under international frequency allocation guidelines, ORBCOMM services can use these frequencies throughout the world....The frequencies requested by ORBCOMM are already allocated to satellite services internationally, so that the only modification required would be to specify that the provision of low-speed, mobile data services is allowed in these bands....The upcoming WARC-92 proceeding provides the mechanism for such an allocation. We urge the U.S. to seek at the WARC-92 the minor changes to the international table of frequency allocations that will allow global operation. [Ref. 77:p. 18]

3. <u>Justification for Prompt Consideration</u>

The Commission was requested to act quickly on the petition because the technology proposed by ORBCOMM could be duplicated by other nations:

> Although we believe that ORBCOMM, an American company, presently leads the rest of the world in development of the technology needed to construct, launch, and operate a low-earth orbiting satellite system, it is by no means clear that this current U.S. advantage will continue past the next two to three years. If the Commission allows others to use the regulatory approval process to delay this service, or if the regulatory process itself needlessly delays the ORBCOMM system, than other countries may surpass ORBCOMM and deploy systems before implementation in the U.S., eliminating the potential foreign trade benefits, and even potentially threatening the provision of service within this country by U.S. suppliers.
>
> At present, at least nine other nations (including the Soviet Union, United Kingdom, India, Israel, and Brazil) have or are pursuing the development of launch vehicles capable of placing small satellites into low-earth orbit. Several countries have or are developing small satellites. Attendant with ORBCOMM's filing of its application for construction of the low-earth orbit satellites and this petition, the commercial potential for a low-orbit mobile satellite system (and supporting documentation) will become public knowledge. Other nations developing launch vehicles can be expected to try to copy ORBCOMM's plan, and might succeed and deploy their system first if ORBCOMM is delayed by the regulatory process in the U.S. Thus, failure of the Commission to act promptly could nullify current American preeminence in this field and forfeit substantial, potential foreign trade benefits from the export of ORBCOMM services and technology. [Ref. 77:pp. 17-18]

4. <u>Effects of Competition</u>

Because of its service capabilities and cost structure, ORBCOMM expects that its petition will be opposed by alternative system operators:

> ...The United States, however, will loose its pioneering role (and accompanying economic and trade benefits) in bringing this new service to the rest of the world if others

are permitted to take advantage of the regulatory process to delay needlessly ORBCOMM's implementation of the proposed system and services. [Ref. 77:p. 3]

In the last ten years, the Commission has acted to make available additional spectrum for a variety of mobile communications services, including cellular telephone service, nationwide paging, RDSS services and MSS services. The public has affirmatively responded with demand for each of the services as they were brought to market. To some extent, the ORBCOMM system will compete within these markets, and will thereby put pressure on all service providers to reduce costs, improve service and reduce prices. This is the marketplace at work. As a result of this potential competition, we expect that this application will be opposed by many service providers who will consider the ORBCOMM system to be a threat to their market positions.

ORBCOMM prefers to compete in the marketplace (not at the Commission), and ORBCOMM is willing to put its capital at risk to meet the needs of unserved and underserved markets. No other system provides the unique combination of features ORBCOMM will provide. We intend to reach consumers at the low end of the price scale with service not available to them now and unlikely to be provided in full by any other technology.... [Ref. 78:p. 23]

5. Licensing

ORBCOMM requested it be granted a "Modified Primary" status, whereby it would not be allowed to cause any interference to other primary users of the frequencies. Under this scenario, ORBCOMM would be granted "primary" status with regards to any future applications for spectrum in the same frequency ranges, and would therefore be protected against future interference. ORBCOMM proposed a blanket licensing for type-approved terminals [Ref 77:pp. 19-24]. This petition is pending before the FCC.

L. OBSERVATIONS ON THE REGULATORY PROCESS

The author spent several days at the Federal Communications Commission while researching this thesis. The FCC staff were exceptionally helpful and professional. System proposals and related public documentation were reviewed. Most of these proposals probably cost well over $100,000 because of the depth of engineering analysis, market studies, and the fees associated with legal representation by firms specializing in communications law. These public filings not only provide detailed information to the Commission, they also enable potential competitors and existing spectrum stakeholders to obtain technical and economic intelligence free of charge, although in some cases authors withheld "proprietary" marketing and financial information.

The petitioner's expenditure of funds, particularly to communications law firms, does not stop at this point. Filing a proposal also initiates a public process whereby <u>any</u> individual or organization is able to provide comments to the Commission. Technical, regulatory, and economic critiques (some of which seem to be spurious, intended to cloud the issues, or maintain the status quo) from other parties often require extensive rebuttal arguments from the petitioner.

The FCC staff is placed in the position of evaluating extensive amounts of written material and making recommendations to the Commissioners as to which types of systems and frequency allocations are in the long-term best public

interest. This entire process takes time, and the need for the Commission to act expeditiously was a recurring theme expressed in some proposals. In cases such as Qualcomm and Geostar 2C, which did not involve major technical or frequency allocation issues, the Commission granted licenses in about a year. RDSS licenses took around two years (although no international frequency allocations for RDSS existed until the conclusion of the 1987 WARC), while roughly six and a half years elapsed between NASA's MSS proposal and award of AMSC's license. As discussed above, one of the major thrusts of ORBCOMM's low-orbit MSS proposal is a request for quick Commission approval because ORBCOMM could possible loose its technological advantage to other nations who are developing their own low-orbit launch and satellite capability.

M. CONCLUSION

To the advocates of new or expanded RDSS and MSS systems, delays of any kind equate to additional expenses and potential loss of market share to competing space and earth-based systems. With FCC licensing being one of the critical success factors (the other is financing) of any new or expanded satellite communication system, it is easy to understand the viewpoint that federal and international regulation are major barriers to system implementation.

However, the regulatory history discussed above shows that the FCC has been supportive of the implementation of RDSS and

MSS systems. Additionally, U.S. Government negotiators at the 1987 Mobile WARC were aggressive in pursuing new international frequency allocations. They refused to capitulate to L-Band stakeholders and other vested interests who discounted technology which allows MSS frequencies to be dynamically allocated based on priority of use. The FCC took a similar approach in its February 1990 Notice of Proposed Rule Making (NPRM), where an additional 33 MHz of L-Band spectrum would be designated within the U.S. for "generic" MSS services.

In rendering its decisions, the FCC takes into account the domestic public need, the critical shortage of spectrum, technology and economic issues, and the international ramifications. This time-consuming administrative process is intended to ensure that all viewpoints are heard and that decisions rendered are in the best long-term public interest. One of the challenges faced by the FCC is to speed up and streamline its regulatory approval procedures to reduce both the time and legal cost. This is of particular importance where the U.S. competitive advantage is at stake. U.S. communications and space industries have come under increased competitive pressure as other nations have increased their own technological capabilities. As pointed out in the ORBCOMM proposal, other governments' philosophies on cooperation and sponsorship of high technology programs can jeopardize the technological leadership enjoyed by some U.S. firms.

VII. CONCLUSIONS

A. REVIEW

Society is increasingly dominated by technology and flows of data in this "information age." This thesis was written to provide the reader with a basic understanding of the technological, economic, and regulatory issues encompassing advanced technology mobile communications. The main points and conclusions of each chapter are reviewed and amplified below.

1. Technological Development and Impact

As a result of technological advancement, particularly in the area of very large-scale integrated (VLSI) circuits, mobile communications equipment has become very sophisticated. What a few years ago required entire racks of equipment and large amounts of electrical power has been reduced to a small device capable of being powered by rechargeable batteries or a 12-volt vehicle electrical system. A continuum of mobile radio frequency equipment has appeared. Terminals range from small low-power, hand-held devices for data exchange and voice communication within the local area to nationwide networked terrestrial and mobile satellite systems.

The emerging capabilities of networked terrestrial and mobile satellite systems enable types of communications that were generally unheard of prior to the mid-1980's. To take

full advantage of these new systems requires a paradigm shift. Users should think in terms of inefficiencies, once an absolute given, that can now be reduced or virtually eliminated because of uninterrupted mobile communications and data flow. Advanced mobile communications systems can become an extension of the organization's management information system. Not only can this make the firm's operations more efficient and effective, it can be used as a sales and marketing tool to provide market differentiation and value-added services.

As discussed in Chapter II, IBM's mobile data system was reported to pay for itself in less than two years, and has a projected cost avoidance of around $500 million over a ten-year period. Federal Express's mobile data system is one of the major reasons for that firm's success. Customers and management enjoy the ability to track and trace shipments in almost real-time. Both of these systems are crucial elements in overall corporate strategy and have helped these firms remain at the forefront of their respective industries.

2. Cost Structures

Fully-allocated user costs, consisting of equipment and service charges, are highly dynamic because of the relative infancy of these systems. As discussed in Chapter III, existing nationwide mobile communications systems have generally been priced according to their services and features. These costs can be expected to change with the

fielding of new systems, production economies of scale, the introduction of new technologies which decrease the per-unit cost of service, and competition.

Long-run user costs and supplier profitability are dependent on the number of terminals and the degree of communication system loading.

a. Terminal Costs

Amortized terminal expenses are an important component of the users' fully-allocated costs. As evidenced by the rapidly declining cost of cellular telephones, mobile terminal expenses are highly dependent on production volume efficiencies and continuously improving technology. As is discussed in Chapter II, the cost of owning a cellular phone has declined at a greater rate than the service charges. This reduction in terminal cost has been a major factor in stimulating demand for cellular service.

The same general cost principal holds for other types of terrestrial system terminals. Meteor burst, networked SMR, mobile data, and nationwide paging all use core technologies and simple antennas which are associated with existing high production volume, conventional local-area VHF and UHF communication systems. The major difference is the internal software and specialized circuitry which allows multi-channel roaming operation. As a result, the production costs for these types of equipment are far lower than if they

were designed and produced exclusively for a nationwide communication service.

The opposite can be said of mobile terminals which use geostationary satellites. Part of the increased expense of mobile satellite terminals is associated with the specialized circuitry and antennas required to surmount the signal spreading loss over a 35,800 kilometer (22,250 mile) path. Most of the technology used for these higher frequency L, S, C, and Ku-band systems (such as the circuitry for spread-spectrum, forward-error correction, and low bit rate vocoders) is relatively specialized. Since mobile satellite terminals do not generally have preexisting and high volume terrestrial counterparts, their per-unit production cost and amortized expense for research and development are much higher. As discussed in Chapter V, satellite system providers are relying on forecasted production economies of scale and accelerating consumer demand to ultimately reduce the costs of terminals to a level of around a thousand dollars or less.

Low-orbit mobile satellite systems, such as the configuration proposed by ORBCOMM (discussed in Appendix A), are able to use conventional VHF and UHF equipment and low-gain omnidirectional antennas. Because of these characteristics, users would probably benefit from reduced terminal expenses.

b. Infrastructure Costs

Repayment of the investment costs in the communications infrastructure is a major element of the user service charge. Since the quantity of equipment used in the system infrastructure is much less than the number of terminals supported, production volume efficiencies will not be as great. For example, the number of <u>conventional</u> cellular telephone sites to mobile phones ranges from a minimum ratio of 1:200 for single-cell rural sites to as high as 1:1200 in the densest urban areas. The concept is similar with the other terrestrial systems.

Networked cellular and SMR systems have the added advantage that most, if not all, of the fixed-site cost is covered by the subscribers in the local area. Most of the incremental cost of forming a nationwide network is associated with buying additional hardware, software, and connecting the individual sites together via telephone or packet-switched networks. With the ARDIS mobile data system, most of the incremental costs will be linked to the additional capacity required to handle increases of traffic. The costs of developing a nationwide network using existing sites, equipment, and preexisting voice and packet communication circuits are far less than building an entirely new system site by site. As such, the subscriber revenues required to repay the incremental investment will be much lower.

The issues facing systems which use communication satellite transponders or add-on packages are similar. Because only a portion of a satellite is used, the pro-rata cost per user at reduced population levels is lower than with a dedicated satellite system. Technical and business risk is also reduced. However, as the total user population increases, eventually a point is reached where it is more economical and service effective to use dedicated satellites.

With the orbiting of only three or four satellites per system over the Americas, major production quantity, launch, and insurance cost efficiencies will be difficult to obtain and pass on to users. However, because the path through the satellite to the ground stations is the network, most of the recurring expenses associated with networked terrestrial systems are eliminated.

As a result of lower terrestrial and satellite system infrastructure production volume efficiencies, major user-cost reductions will come about only as a result of increasing the volume of communications per terrestrial site or satellite. In the case of earth-based systems, this movement is already underway with the migration of cellular telephone to TDMA and spread-spectrum standards.

3. Market Size and Share

The principal determinant of economic success will be the total market size and market share captured by each system. Based on the comparative service offerings, rates

charged by terrestrial systems, and terminal prices, it is unlikely that most users operating within coverage of a ground-based system would initially choose to use a mobile satellite. Additionally, the limited link margins of mobile satellite systems restricts them to line-of-sight use. This contrasts with portable terrestrial systems, which to a certain extent can be used within buildings and other areas where a direct signal is blocked. With the continuing expansion of ground-based networks and the launching of North American RDSS and MSS systems still a few years off, it will be difficult to realize the full extent of use originally envisioned by the RDSS and DLMSS system proponents. Accordingly, it is probably an overstatement to incorporate estimates of demand for areas covered by earth-based systems into MSS and RDSS market forecasts. Some roaming users may also use networked terrestrial systems if the cost difference is not viewed as justifying uninterrupted service. This will reduce the size of the satellite market even further.

Based on the estimated costs for dedicated satellite systems and the Waters Information Services marketing study [Ref. 60:pp. 35-47] (discussed in Chapter V), the Class I long-haul trucking industry is probably not large enough to support even a single dedicated satellite system. As a result, dedicated RDSS and MSS systems will have to rely on widespread use by Class II and III long-haul carriers and a large base of other users located outside terrestrial coverage

areas. The view that a North American mobile satellite system would have to be shared between aeronautical, mobile, and fixed users appears to be correct.

A critical element in mobile satellite system profitability will be the speed with which the services are adopted. Unlike networked terrestrial systems, which have smaller incremental expansion costs and are generally supported by a local user base, mobile satellite systems require large incremental investments. If the user base is slow to develop, the negative cash flows could be substantial. However, these systems can be quite profitable in the long run if they are capable of achieving a high load factor. In the case of the first-generation North American mobile satellites, leasing interim capacity from INMARSAT is a strategy to build a user base prior to satellite launch.

B. FUTURE SYSTEMS

1. Low Altitude Satellites

As detailed in Chapter V, terminal prices will be a key determinant of market size. For the use of mobile satellite systems to become a consumer service, total user costs will have to lie on the elastic portion of the demand curve. This requires that terminal prices be as low as possible. As discussed above, the antennas and specialized terminal circuitry make this difficult unless very high production volumes can be reached. Traditionally, the

conceptual solution to this problem has been to launch subsequent generations of mobile satellite systems using higher-power geostationary satellites with increased numbers of spot beams.

Low earth-orbit satellite systems, similar in concept to the ORBCOMM proposal discussed in Appendix A, may ultimately be the answer to the terminal cost problem. Spreading loss over the path between the earth and low-altitude satellite is far less than to geostationary orbit, thus allowing simpler mobile-terminal antenna and electronic subsystems. The satellites will also be much less expensive because they do not require sophisticated stabilization, multi-beam antennas, and high-power transmitters. One constellation of satellites can provide service to most, if not all, of the Earth. Because the energy required to reach low-altitude orbit is far lower than required for geostationary orbit, launch expenses per satellite are substantially less. Finally, replacement of failed satellites is less expensive and quicker. Construction of a low-altitude mobile satellite system may require a paradigm shift on the part of system operators, launch providers, satellite manufacturers, and communication regulators.

2. Modulation Types

Because of increasing demands for limited spectrum in both terrestrial and mobile satellite service, most single-channel per-carrier operations will ultimately be replaced by

forms of TDMA or spread-spectrum. The incremental costs of these more sophisticated frequency-sharing methods will decrease with time as integrated circuit processing capability becomes more powerful. Although this will raise terminal prices, the increases in system capacity will result in lower user charges and increased service levels.

C. TRUCKING INDUSTRY USE

As discussed in Chapter I, nationwide communication and tracking technologies have the potential to influence transportation and logistics operations in three main ways. From an administrative standpoint, the ability to track and communicate in almost real-time can lower a firm's costs by reducing the amount of work performed by employees. Operationally, these systems can increase the efficiency and effectiveness of the firm's plant, equipment, and workers. Strategically, the technology has the potential to provide a competitive advantage and enable new, value-added services to be provided to the customer.

Potential is stressed because these benefits will only be realized if they can be put into practice and return some sort of value to the firm or its customers. In the case of irregular route long-haul carriers, these systems may be cost-effective based entirely on the increased efficiencies resulting from more timely flow of information to the dispatcher and a reduction of telephone expenses. As such,

their adoption will probably be the result of a fairly-straightforward economic analysis, ideally using baseline and operational test data.

However, other types of trucking firms may not be able to economically justify the investment in a nationwide communication system based only on the above two points. Fixed-route LTL haulers are a primary example, particularly if their freight terminals and cargo-tracking processes are already well automated and operating efficiently. An exception may be in the area of just-in-time transportation, where the shipper and receiver rely on tight delivery schedules and need to be advised of problems as soon a possible to avoid stockouts and shutdowns. In this case, use of a nationwide mobile communications system is viewed more as an insurance item that one or more parties are willing to subsidize. Efficient niche carriers that serve well-defined markets may also experience lower benefits from an investment in one of these systems.

One way to maximize the benefits of a nationwide communication system is to directly integrate it with the firm's ADP and management information system. Development of adequate software, as well as communicating between different carrier and customer computer systems, can be a major obstacle. Many of the identified potential efficiencies will not come to pass unless communication and information flows are readily available and in a form which frees both the

carrier, the shipper, and the receiver from the tyranny of paperwork and its associated costs.

Prior to acquiring a system, a rigorous analysis of equipment and software alternatives must be conducted, particularly as they relate to the carrier's operating pattern, markets, and competitive strategy. Firms should thoroughly evaluate the difference in costs and benefits provided by earth and space-based systems. Carriers, particularly in this highly competitive deregulated environment, need to avoid the temptation of relying just on the proposals of suppliers and the observation of what equipment seems to be working for other similar trucking firms.

D. POTENTIAL DEPARTMENT OF DEFENSE TRANSPORTATION SYSTEM APPLICATIONS

1. Nationwide and Regional Transportation Systems

DoD administers several air and surface freight transportation networks designed to expeditiously move military cargo within the continental United States. These systems (Logair, Quicktrans, Contruck, etc.) are operated by contractors. In this era of declining defense budgets, the routine airlift of higher-priority material within the continental United States may become a readiness item which the services have difficulty affording. The use of nationwide tracking and communications systems might make it easier to

divert all but the most truly urgent material (TP-1 CASREPS, RDD 999, Greensheet, etc.) to surface express movement.

Dedicated dual driver express trucks would allow loads to be hauled across country in approximately three days, and freight could be moved from geographically-centralized stock points along most costal route segments in around 24 hours or less.[1] Equipping express trucks with nationwide communication and tracking equipment would allow the distribution system to be monitored in almost real-time, and could dispel fears that material will get lost or stranded without prompt action being taken. Exact cargo status and ETA could be provided to interested parties. The scope of the DoD ordnance tracking system, operated by the Navy Material Transportation Office (NAVMTO), could probably be expanded to cover this function without markedly increasing the number of personnel or required hardware. If enough freight is divertable, particularly on the shorter route segments, the use of dedicated cargo aircraft could be reduced or discontinued. The remaining truly-urgent air freight could be transported by airlines and overnight air cargo carriers at negotiated volume discounts.

Taken a step further, the surface-express concept might also be expanded to allow the consolidation of a large

[1]For example, daily direct delivery of material from GSA Stockton (located about 50 miles east of San Francisco) to NSC San Diego (a distance of about 550 miles) routinely takes between 12-14 hours.

amount of lower-demand, geographically-disbursed material at a fewer number of stock points. Due to the inventory model structure (a discussion of which is beyond the scope of this thesis), the <u>total</u> amount of stock within government logistics systems would potentially be reduced, as well as the duplication of costs associated with ordering, receiving, and storage of material at multiple inventory points. This could reduce total-system warehousing expenses, carrying costs, and stock fund obligations, while still enabling timely and low cost per unit delivery.

2. <u>Local Distribution Systems</u>

The use of tracking and communication equipment could also be applied on a micro level to Navy Supply Center local delivery systems. Supply Centers are somewhat unique in that many of their major customers (ships and submarines) can only receive their material when they are in port, and these vessels frequently tie-up at different locations. Direct turn-over receipts from outside sources and material issued from the supply center are routed to stowage bays in transit sheds for consolidation and holding prior to delivery to a customer. Local delivery load-planning and movement of vehicles is governed by a combination of standard operating procedure and supervisor judgment. In view of the new technologies available, this manual system may suboptimize resource usage because of the lack of freight data and the large number of constantly changing variables.

Developing an automated vehicle dispatch system which uses freight data gathered from the Navy NAVADS and NISTARS ADP programs could enable dynamic load planning and scheduling. Vehicle and personnel use could be further improved by equipping each truck with a mobile data and tracking terminal. This would allow both the dispatcher and computer system to know the location and status of the vehicle in real-time, and permit the computer to automatically send dispatch orders to the driver. Should a change of delivery or routing requirements occur, as it frequently does on the waterfront, the computer program could take all remaining planned work into account when suggesting a task order change to the dispatcher. This type of dynamic system might be able to use a modified route-delivery planning and dispatching software package, a number of which are available for use on mini and microcomputers. A system such as this might also have other military service applications, such as ground-force resupply.

E. EPILOGUE

> Many executives of the 1980s abhor the very thought of being out of touch. Some may call the affliction a disease which mobile communications is helping to spread. By the third millennium...the disease may become a global epidemic.
>
> No matter where we happen to find ourselves, we will be plugged in.
>
> The driver of a Land Rover stranded in the middle of the Sahara need not fear. A satellite link will not only determine its position within a few meters, but will allow the driver to summon help.

The business woman flying from Tokyo to Singapore will be able to pause in the middle of her business class aperitif to advise her husband back home on how to quiet down a howling baby.

And that mythical island in the tropics, far from civilization--the place you have always promised yourself you will find when you retire? It will likely be as overridden with communications devices, computers and fax machines as your office.

The technology to realize this future already exists. [Ref. 61:p. 7]

APPENDIX A

EXISTING AND PROPOSED MOBILE SATELLITE SYSTEMS

A. INTRODUCTION

This appendix details the operation of existing and proposed mobile-satellite communications systems. The regulatory aspects of these systems are discussed in Chapter VI.

B. INMARSAT-C

1. Background

The International Maritime Satellite Organization (INMARSAT) was formed in July 1979 to provide worldwide maritime mobile-satellite communications and radiodetermination services. INMARSAT's charter was amended in 1985 to provide for aeronautical mobile-satellite communications, and again in 1989 to permit land mobile-satellite services.

INMARSAT began its service in 1982 by leasing three Marisat satellites from Comsat General, the U.S. signatory. Further capacity was obtained by leasing two Marecs satellites from the European Space Agency and by placing maritime communication packages on three Intelsat satellites. Continued growth in communications traffic required that INMARSAT acquire a second generation of satellites, the first of which will be launched in October 1990. A third generation of INMARSAT satellites is planned to be launched in 1994 to meet expected future demand. [Ref. 79]

Unlike the other operating mobile-satellite service providers (Geostar and Qualcomm), the INM .RSAT system is an open-architecture, shared-use worldwide satellite communications network. INMARSAT provides the space segment and establishes the basic operating standards and specifications. INMARSAT signatories, and other organizations with INMARSAT permission, operate the earth-station gateways which interconnect the space segment with terrestrial communications systems. Although space segment charges are fixed, competition acts to keep the total costs of service down. The user is free to select any earth-station gateway within the operating region and can choose among different manufacturers of mobile terminal equipment. The history and organizational structure of INMARSAT is discussed in more detail below.

2. <u>History and Organizational Structure</u>

a. Initial Agreements

In 1973, The Assembly of the Inter-Governmental Maritime Consultative Organization decided to convene an international conference to discuss the principle of setting up an international maritime-satellite system. The International Conference on the Establishment of an International Maritime Satellite System met three times during 1975 and 1976 to conclude the INMARSAT Convention and Operating Agreements and set up the basic organization and structure of INMARSAT.

The Preamble to the Convention stated:

> CONSIDERING the principle set forth in Resolution 1721 (XVI) of the General Assembly of the United Nations that communication by means of satellites should be available to the nations of the world as soon as practicable on a global and non-discriminatory basis,
> CONSIDERING the relevant provisions of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, concluded on 27 January 1967, and in particular Article 1, which states that outer space shall be used for the benefit and in the interests of all countries,
> TAKING INTO ACCOUNT that a very high proportion of world trade is dependent on ships,
> BEING AWARE that considerable improvements to the maritime distress and safety systems and to the communication link between ships and between ships and their management as well as between crew or passengers on board and persons on shore can be made by using satellites,
> DETERMINED, to this end, to make provision for the benefit of ships of all nations through the most advanced suitable space technology available, for the most efficient and economic facilities possible consistent with the most efficient and equitable use of the radio frequency spectrum and of satellite orbits.... [Ref. 80:p. 11]

The function of INMARSAT was defined in Article Three as:

> (1) The purpose of the Organization is to make provision for the space segment necessary for improving maritime communications, thereby assisting in improving distress and safety of life at sea communications, efficiency and management of ships, maritime public correspondence services and radiodetermination capabilities.
>
> (2) The Organization shall seek to serve all areas where there is need for maritime communications.
>
> (3) The Organization shall act exclusively for peaceful purposes. [Ref. 80:p. 12]

As shown in Figure 92, governments agreed to a three-tier organization structure. The highest level, the Assembly of Parties, is composed of representatives from each of the member governments. The Assembly meets every two years

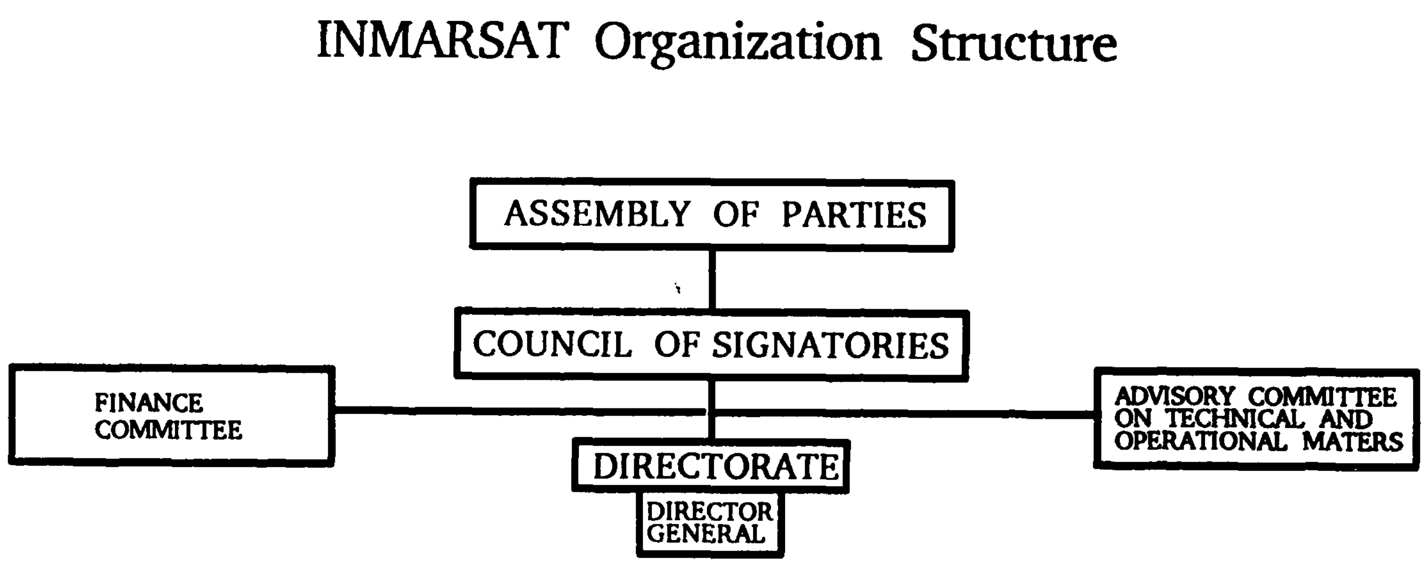

Figure 92. INMARSAT Organization Structure

to review the activities, purposes, and objectives of INMARSAT. Each party has one vote, regardless of the investment share of its Signatory. [Ref. 80:p. 16]

The Council, composed of 22 Signatories to the INMARSAT Operating Agreements, has similar functions to a corporation's board of directors. Eighteen of the members represent those Signatories or groups of Signatories which have the largest investment shares. Four members are elected by the Assembly irrespective of investment share. This is to be sure, among other things, that the interests of developing nations are addressed. Voting participation is equal to investment share, generally not to exceed 25% of the total voting participation. Decisions of a substantive matter require a two-thirds majority. The Council meets a minimum of three times a year, and is aided by a finance committee and a technical committee. [Ref. 80:pp. 17-20]

The third tier is the Directorate, which controls the operation of INMARSAT. The Director General is the chief executive and legal representative of the organization. [Ref. 80:pp. 20-21]

Signatories agreed to initially finance INMARSAT through capital contributions. A portion of the revenues earned by the organization are used to compensate each Signatory for use of investment capital and to repay the initial investment. Subsequent investment shares are periodically determined on the basis of percentage utilization

of the INMARSAT space segment by all signatories, and the appropriate financial adjustments are made according to a formula. Revenues earned by INMARSAT are derived only from the use of the space segment. The rates charged for each type of service are the same for all signatories. Payment of space segment charges to INMARSAT is the responsibility of the Signatory or authorized telecommunications entity through which the ground portion of the communication is routed. No provision is made to regulate the cost of the ground segment or override the provisions of the International Telecommunications Convention and the International Telecommunication Union [Ref. 80:pp 38-50]. Figure 93 illustrates INMARSAT's financing and cash flow [Ref. 67:p. 262].

The INMARSAT Convention and Operating Agreement entered into force on 16 July 1979. The largest initial investment shares were held by the United States, the United Kingdom, and the Soviet Union [Ref. 80:p. 49].

b. Recommendations of the International Conference

The conference held in 1975 and 1976 recommended that worldwide minimum technical standards be established for operations within the INMARSAT system. This would allow significant economic, operational, administrative and technical advantages to be gained, and ensure that all mobile terminals could communicate with land subscribers. The conference also recommended that each country allow INMARSAT mobile terminal transmissions within its territorial waters

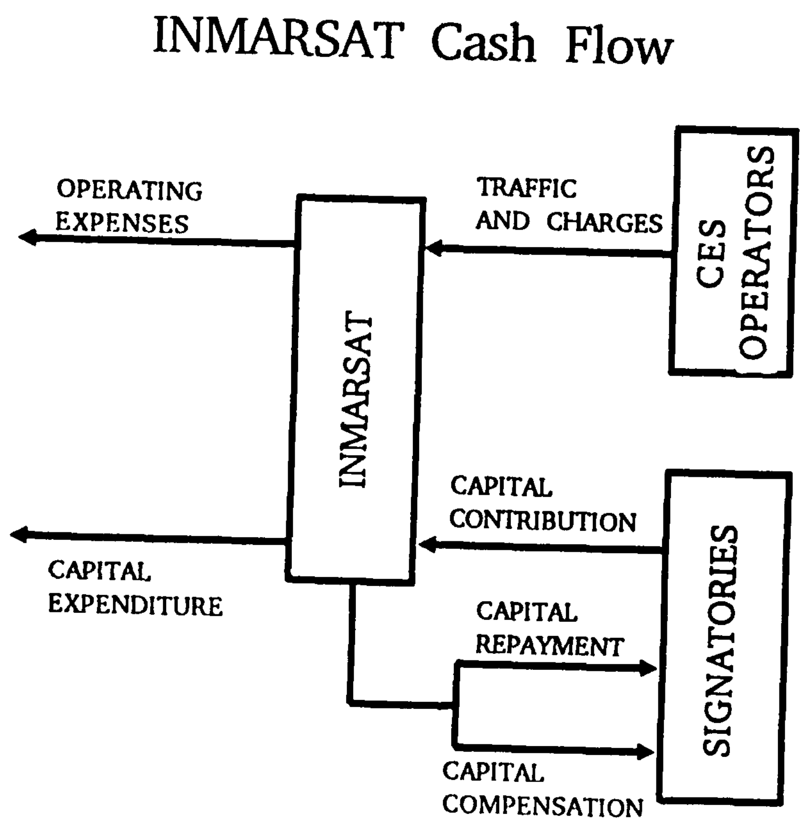

Figure 93. INMARSAT Cash Flow

and harbors. This would improve ship management efficiency, ship-to-shore communications and safety services, and encourage procurement of equipment to use the INMARSAT system. Finally, the conference recommended that a study be undertaken on the use of multi-purpose satellites to provide both maritime mobile and aeronautical mobile services. [Ref. 80:pp. 54-55]

c. Subsequent Amendments

The INMARSAT Assembly, at its Fourth Session held in October 1985, adopted amendments to the Convention and Operating Agreement to include the provision of aeronautical satellite communications services [Ref. 67:p. 64]. These amendments were later ratified. In January 1989, the Sixth Extraordinary Assembly of INMARSAT Parties adopted further amendments to the INMARSAT Convention and Operating Agreement to provide for land mobile-satellite communications. Pertinent sections of the Preamble were rewritten:

> TAKING INTO ACCOUNT that world trade is dependent upon transportation by sea, air and on land,
>
> AFFIRMING that a maritime satellite system shall also be open for aeronautical and land mobile communications and communications on waters not part of the marine environment for the benefit of all nations.... [Ref. 81]

The function of INMARSAT was also revised:

> (1) The purpose of the Organization is to make provision for the space segment necessary for improving maritime communications and, as practicable, aeronautical and land mobile communications and communications on waters not part of the marine environment, thereby assisting in improving communications for distress and safety of life, communications for air traffic services, the efficiency and management of transportation by sea, air and on land,

maritime, aeronautical and other mobile public correspondence services and radiodetermination capabilities.

(2) The Organization shall seek to serve all areas where there is need for maritime, aeronautical and other mobile communications. [Ref. 81]

3. Service Overview

INMARSAT provides a variety of services. INMARSAT-A is a highly flexible system that permits various grades of two-way voice, telex, data, and fax communication. INMARSAT-A uses a stabilized parabolic antenna that is about one meter in diameter, so its use in a mobile environment is generally restricted to larger ships. INMARSAT-A is also employed in fixed locations, such as offshore oil platforms, and provides transportable news coverage and emergency disaster communications. Costs for INMARSAT-A terminals and antennas range from $30,000 to $40,000. Voice communications through COMSAT land earth stations cost approximately $10.00 per minute to any destination within the U.S. and Puerto Rico. Calls to other areas are priced higher. At the end of 1989 there were over 10,000 INMARSAT-A terminals in operation.[1]

INMARSAT-B is a developmental digital-voice companion and eventual replacement for INMARSAT-A. INMARSAT-M is a digital voice, fax, and data terminal designed for small vessel and land-mobile use. INMARSAT-M will use low-cost components, a small antenna, and requires the higher power

[1]Telephone conversation between Mr. Jim Jansco, COMSAT, and the author, 16 May 1990.

INMARSAT 2 satellites. INMARSAT is also implementing aeronautical services for airborne communication and air traffic surveillance and control. A more detailed discussion of INMARSAT A, aeronautical services, and the developmental B and M systems are beyond the scope of this thesis.

INMARSAT-C is a low-cost, two-way store and forward packet data system which uses a small omnidirectional antenna. This permits INMARSAT-C to be easily installed aboard land vehicles, small boats and yachts, and to be used for remote monitoring and control. INMARSAT-C came into use in 1989. In early 1990, costs ranged from $4000 to $6000 for a basic INMARSAT-C terminal. Depending on the options (such as personal computer, navigation receiver, etc.), costs for INMARSAT-C terminals could go as high as $9000. Costs for INMARSAT-C message and data transfer via COMSAT land-earth stations are expected to be approximately $1.05 per kilobit (125 bytes) from a mobile to a base station. Base station to mobile messages will cost around $1.25 per kilobit. A 256 byte data report message from a mobile unit is expected to cost $0.10. These costs include movement via a packet-switched network anywhere throughout the 50 states and Puerto Rico. Charges to other areas are higher. No monthly subscription fees are anticipated.[2]

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[2]Telephone conversation between Mr. Jim Mansco, COMSAT, and the author, 16 May 1990.

4. <u>INMARSAT-C Configuration</u>

Figure 94 illustrates the general configuration of INMARSAT-C [Ref. 67:p. 93].

a. User Terminals

INMARSAT-C terminal costs are reduced by using a small, lightweight omnidirectional antenna and relatively low power digital packet transmissions. As shown in Figure 95, the data-circuit terminating equipment (DCE) consists of the antenna, transmit, receive, and associated control electronics. The DCE, which interfaces with the satellite network, is connected via standard input/output (I/O) ports to the user interface or data terminal equipment (DTE) [Ref. 82:p. 2]. DTE can be laptop and standard-sized personal computers, ASCII terminals, printers, and custom "black boxes" for data interchange. Terminal position information can be automatically provided by an external navigation receiver, such as Loran-C, Transit, GPS, or other equipment which has a built in I/O port. The DCE and DTE together make up a mobile-earth station (MES). [Ref. 83:p. 4]

INMARSAT-C terminals operate in the L-band. They transmit on 1626.5 MHz to 1646.5 MHz and receive from 1530 MHz to 1545 MHz. Tuning is in increments of five Khz. Time-division multiplexing (TDM) and binary phase-shift keying (BPSK) modulation are used. Forward-error correction (FEC) and 16 bit-packet data checksums are used to ensure correct message reception. The mobile terminal transmission rate is

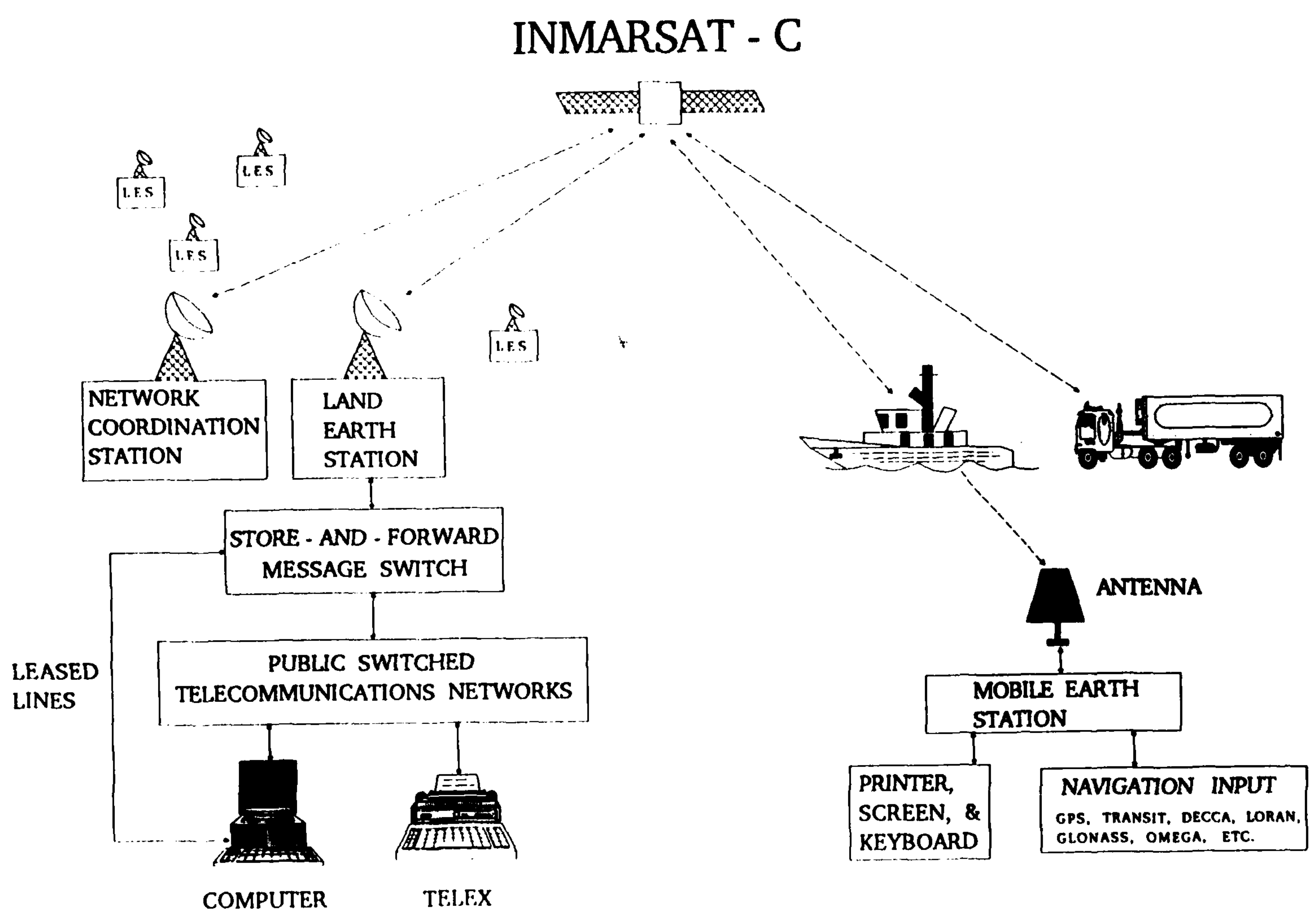

Figure 94. INMARSAT-C

INMARSAT - C
Mobile Earth Station (MES)
Block Diagram

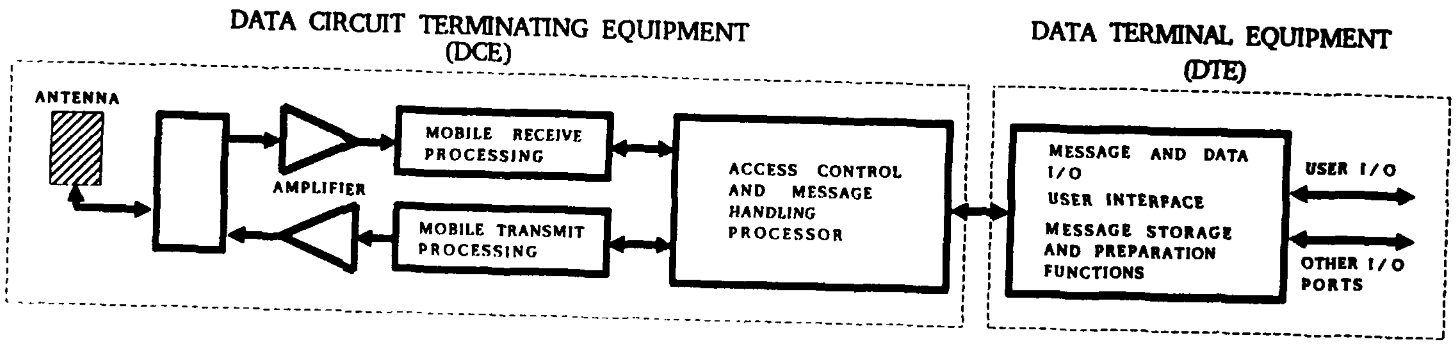

Figure 95. INMARSAT-C Mobile-Earth Station (MES) Block Diagram

300 bits per second (bps) when using first generation satellites. The second and third generation INMARSAT satellites will allow transmissions at 600 bps. Reception using current and future satellites is at 600 bps. [Ref. 84:p. 2]

INMARSAT-C terminals have unique electronic addresses and incorporate Enhanced Group Call (EGC) functions. This allows the distribution of messages to any specified group of terminals or to terminals located in any geographical area. Polling commands can also be used to initiate a mobile terminal position or data report. [Ref. 83:pp. 4-5]

As an example of INMARSAT-C terminal size and weight, the unit manufactured by Thrane and Thrane (pronounced Tron and Tron) in Denmark uses a 2 kg (4.4 lbs) antenna which is 28 cm (10.5 in) high and measures 19 cm (7.5 in) in diameter. The enclosure containing the data circuit terminating equipment is around 25 cm long x 25 cm wide x 7.5 cm high (10 in x 10 in x 3 in) and weighs 3.5 kg (7.7 lbs). [Ref. 85]

b. Space Segment

INMARSAT uses a constellation of satellites spaced about 120 degrees apart to provide worldwide coverage. Each operating region has at least one spare satellite. The first and second generation satellites use global beams to illuminate the earth, and act as a "bent pipe" to relay communications traffic. The third generation satellites will

feature onboard message switching, global beams, and higher power spot beams.

Communication between mobile-earth terminals and satellites takes place in the L-band (1.53 GHz to 1.64 GHz), and satellite to fixed earth-station links are at C-band (4.19 GHz to 6.43 GHz). Figure 96 illustrates the approximate locations and earth coverage of INMARSAT first generation satellites.

c. Ground Segment

As shown in Figure 97, overall control of the INMARSAT network is administered by the operations control center (OCC). The OCC is linked to three satellite control centers (SCC), which are responsible for the physical management of the three different types of first generation satellites. The second and third generation satellites will be controlled directly by INMARSAT from its London headquarters. The OCC is also tied to three regional network coordination stations (NCS). These interconnected stations govern the overall operation of the system within their operating area. The land-earth stations (LES) serve as a gateway between terrestrial communications systems and the satellite [Ref. 67:pp. 102-103]. LESs perform a store and forward function, where data and messages are received and held in an "electronic mailbox" before delivery to the mobile terminal or insertion into a terrestrial communications network. The store and forward feature acts as a buffer.

Approximate Earth Coverage of
INMARSAT First Generation Satellites

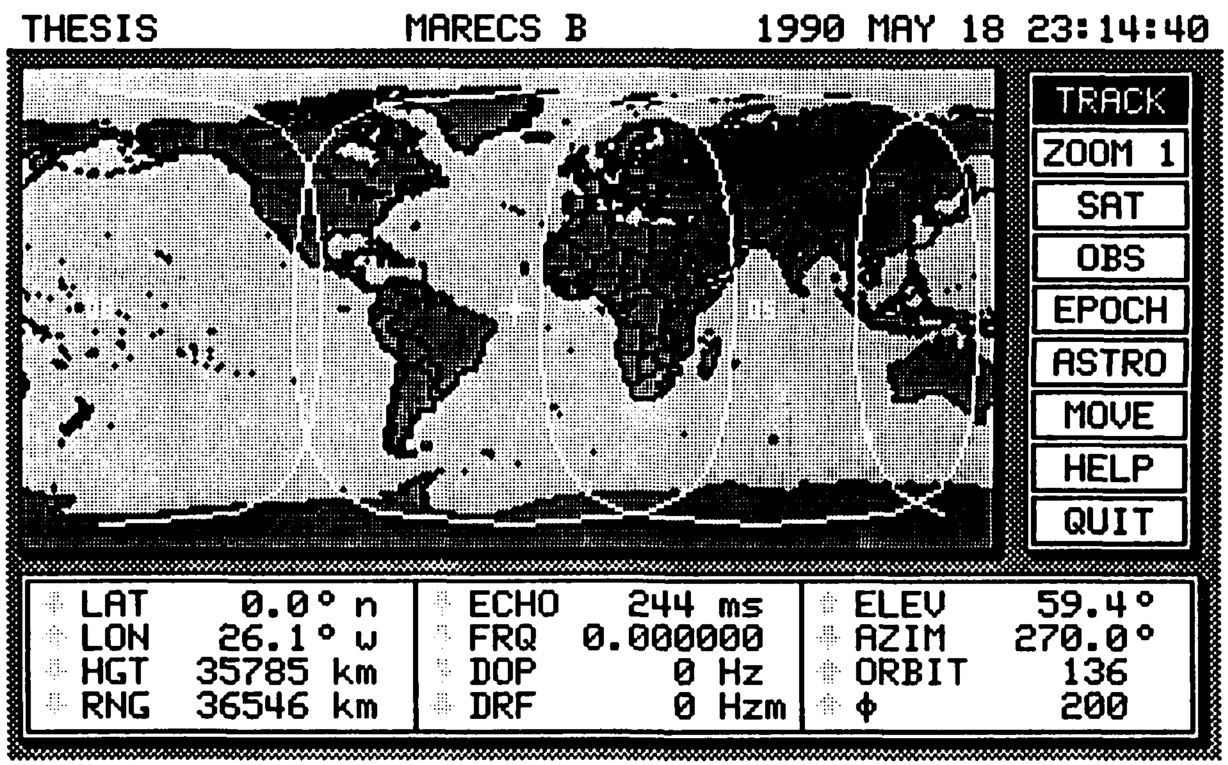

Figure 96. Approximate Earth Coverage of INMARSAT First Generation Satellites

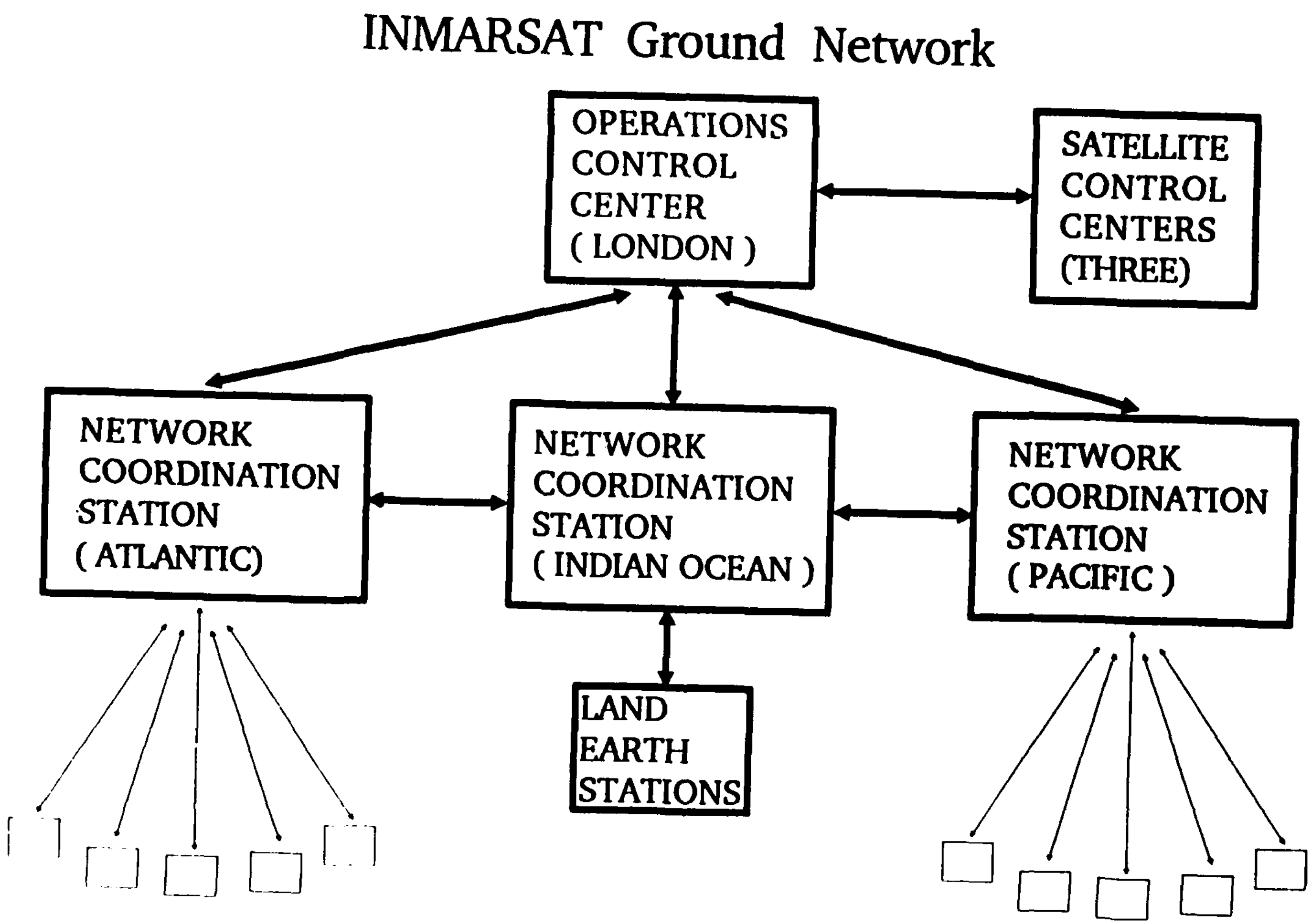

Figure 97. INMARSAT Ground Network

This allows connection with any terrestrial communication system which uses standardized communication protocols and data transfer rates. The LESs can be tied into the public switched telephone network (PSTN) for voice-band data transfer via a modem, packet-switched data networks (PSDN), the TELEX system, and other private communication networks. [Ref. 83:p. 4]

d. INMARSAT-C Network Architecture

INMARSAT C network architecture is more complex than single-region, single-hub networks. This is because of the requirement for a global coverage system and number of land-earth stations which interconnect with terrestrial communications networks. As illustrated in Figure 98, within each area the NCS, LES, and MES make up a three-node network [Ref. 82:p. 1]. This requires a range of frequencies and several time division multiplex (TDM) data control and message channels.

TDM systems separate users by time. The major division of time is called a frame, with minor divisions known as slots. TDM and the random-access protocol known as slotted ALOHA are discussed in greater detail in Appendix B.

(1) NCS Common Channel. The NCS common channel is broadcast continuously by the NCS to all mobile terminals in the region. Each terminal tunes to this frequency except when involved in message transmission or reception. The NCS common channel is divided into frames 8.64 seconds long with

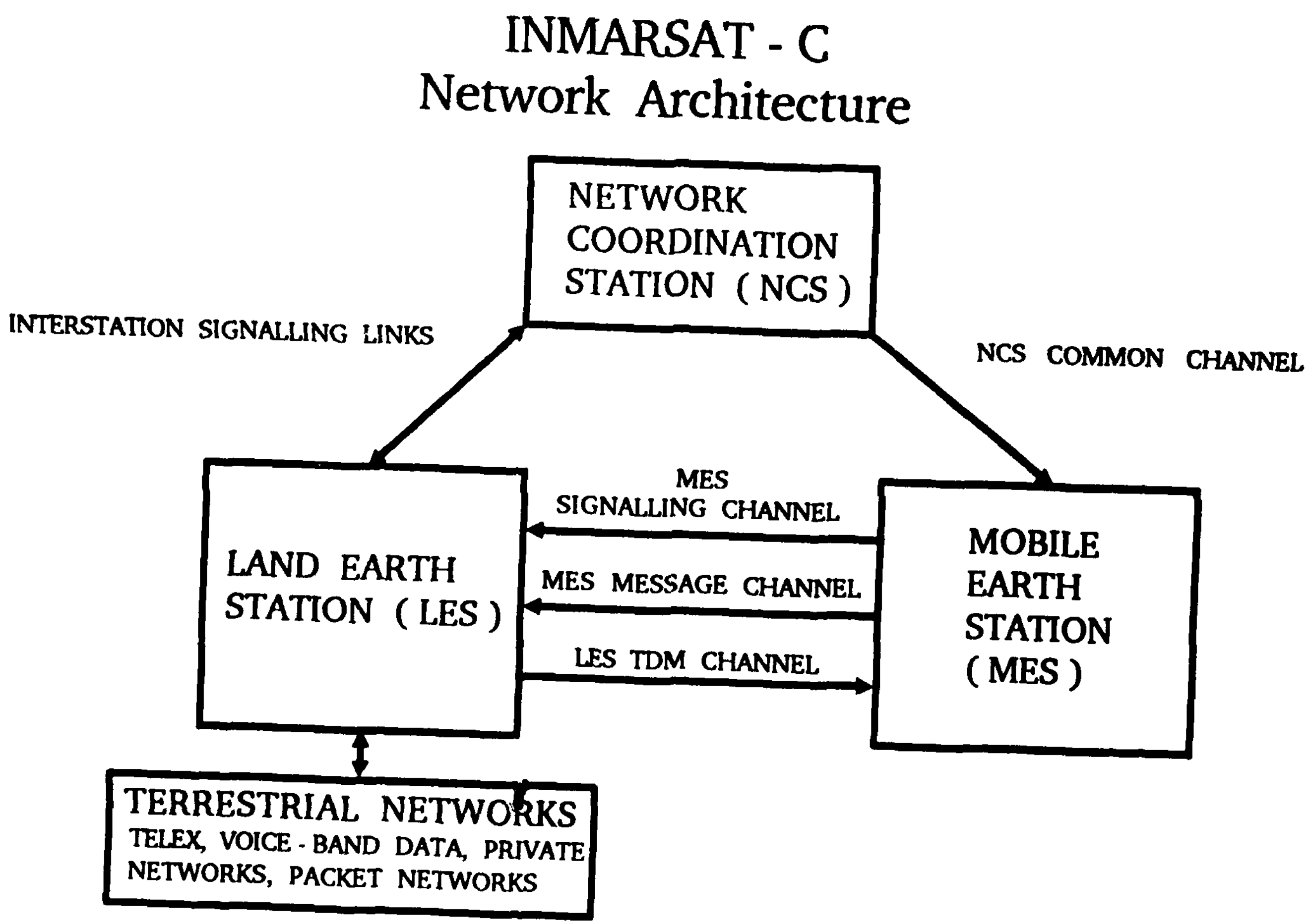

Figure 98. INMARSAT-C Network Architecture

a data rate of 600 bits per second. There are 639 bytes per frame available for data packets. The NCS common channel is used to assign terminals to the LES which has received a message for relay, for broadcasting polling and enhanced group call (EGC) messages, and to confirm idle status with mobile terminals released from a LES.

(2) LES TDM Channel. This channel is used when a LES is communicating with a terminal. It is used for conveying call set-up signals, base-to-mobile messages, terminal message acknowledgements, and call take-down signals. Its structure is the same as the NCS common channel.

(3) MES Signalling Channel. The MES signalling channel is used by the mobile terminal to randomly access the LES via a modified slotted-ALOHA protocol. This occurs when the MES wants to reply to a poll, EGC, or message announcement broadcast by the NCS, or when the MES operator wants to send a message or position report.

Slot timing is based on 8.64 second TDM frames, with each frame divided into 14 slots for first generation satellites and 28 slots for second and third generation satellites. Each slot can carry 120 data bits.

(4) MES Message Channel. This TDM channel is used by the terminal to send data messages. Transmit start time is governed by the LES and conveyed to the terminal over the LES TDM channel. To increase throughput on this channel, more than one TDM frame size is available. A frame may

contain between one and five packets, with each packet containing 127 bytes of information.

(5) Interstation Links. Each NCS is connected to all land-earth stations within the region. This two-way link is used to transfer call announcements and EGC messages from a LES to the NCS for transmission on the NCS common channel. The link is also used for the control of LESs by the NCS.

(6) Interregional Links. Each NCS is connected to the other NCSs, primarily to update the other two regions when a MES enters the region and logs into the network. [Ref. 84:pp. 3-4]

5. INMARSAT-C Operation

a. User Terminals

For mobile-to-base messages, the data is formatted in the data terminal equipment (DTE) and transferred to the data circuit terminating equipment (DCE). The DCE holds the data in memory until directed to send it to the LES. For base-to-mobile messages, the DCE receives the complete data message and then passes it to the DTE.

b. Space Segment

The satellite receives the uplink signals, translates their frequencies from L to C-band (mobile to LES) and from C to L-band (LES to mobile), and rebroadcasts the signals on the downlink.

c. Ground Segment

The OCC receives reports on how the satellite and land-earth stations are performing, and monitors traffic loading throughout the system. The OCC issues operational information and is responsible for coordinating the changeover of traffic from an operational to spare satellite. The OCC also maintains a database on all mobile and fixed terminals which are authorized to use the INMARSAT system.

All MESs within the geographic region are required to register with the controlling NCS. The NCS authorizes access to the regional network and passes the registration information to each LES under its control and to the other NCSs.

The NCSs use computers to monitor land-earth station operating performance and all communications which flow through the satellite servicing the operating region. If traffic loading and satellite power consumption reach certain levels, the NCS's computer system will take over the function of allotting frequencies and time assignments to mobile terminals and land-earth stations. This two-tier control system increases network throughput at high usage levels.

The land-earth stations normally allocate frequencies and time assignments in response to message relay requests from mobile-earth stations and terrestrial base stations. As discussed above, the LESs will yield this function to the NCS if communication loading or satellite

power consumption reaches certain levels. The LES maintains a list of all registered users to determine if a call should be accepted or rejected. The call will be refused if a message is received from or to an unauthorized MES. [Ref. 83:p. 3]

d. Channel Access

To maximize communications capacity, all three nodes in a region are part of a time-synchronized network. The NCS and LES computers control the sequence and timing of their outbound transmissions. Likewise, upon request they also instruct the MES with the time and frequency to transmit on.

Although all nodes are synchronized, the mobile terminal must first enter the system by randomly transmitting into a frame and slot on the MES signalling channel. As a result, it is possible for two or more terminals to randomly transmit into a slot at the same time. This will result in a "collision" as seen by the LES. To reduce the chance of this occurring, only the first packet is randomly sent into a slot. The remainder is transmitted on an assigned MES message channel and time as commanded by the LES over the LES TDM signalling channel.

To quickly advise a terminal that its transmission collided with another, the LES TDM signalling channel lists the status of all the slots in the previous MES signalling frame. If the slot in which the MES transmitted is coded as

"collision" or "vacant," the MES will automatically retransmit its request. [Ref. 83:p. 11]

e. Call Set Up and Message Transfer Procedures

A fixed station originated call is illustrated in Figure 99. The fixed user places a call to the MES. The call is routed via the terrestrial network to the designated LES, where the location of the MES is verified. If the MES is within the geographic region, the LES sends a message to the NCS requesting that a call-waiting announcement be broadcast to the coverage area. The announcement directs the called MES to tune to the proper LES TDM channel. The MES tunes to the new frequency, synchronizes frames and determines the frequency of signalling channel monitored by the LES. The MES responds to the LES by transmitting into one of the signaling channel random-access slots. The LES then sends the stored message over the LES TDM channel. The MES acknowledges receipt, and requests retransmission of any incorrectly received packets. Following successful transfer, the MES is released back to the NCS common channel and the NCS is advised. [Ref. 82:p. 4]

Figure 100 is a sequence diagram for a MES originated call to a LES for a message transfer. The MES, which is monitoring the NCS common channel, retunes to the desired LES TDM channel and synchronizes frames. The MES then sends a request into one of the random-access slots on the MES signalling channel. The LES checks the terminal

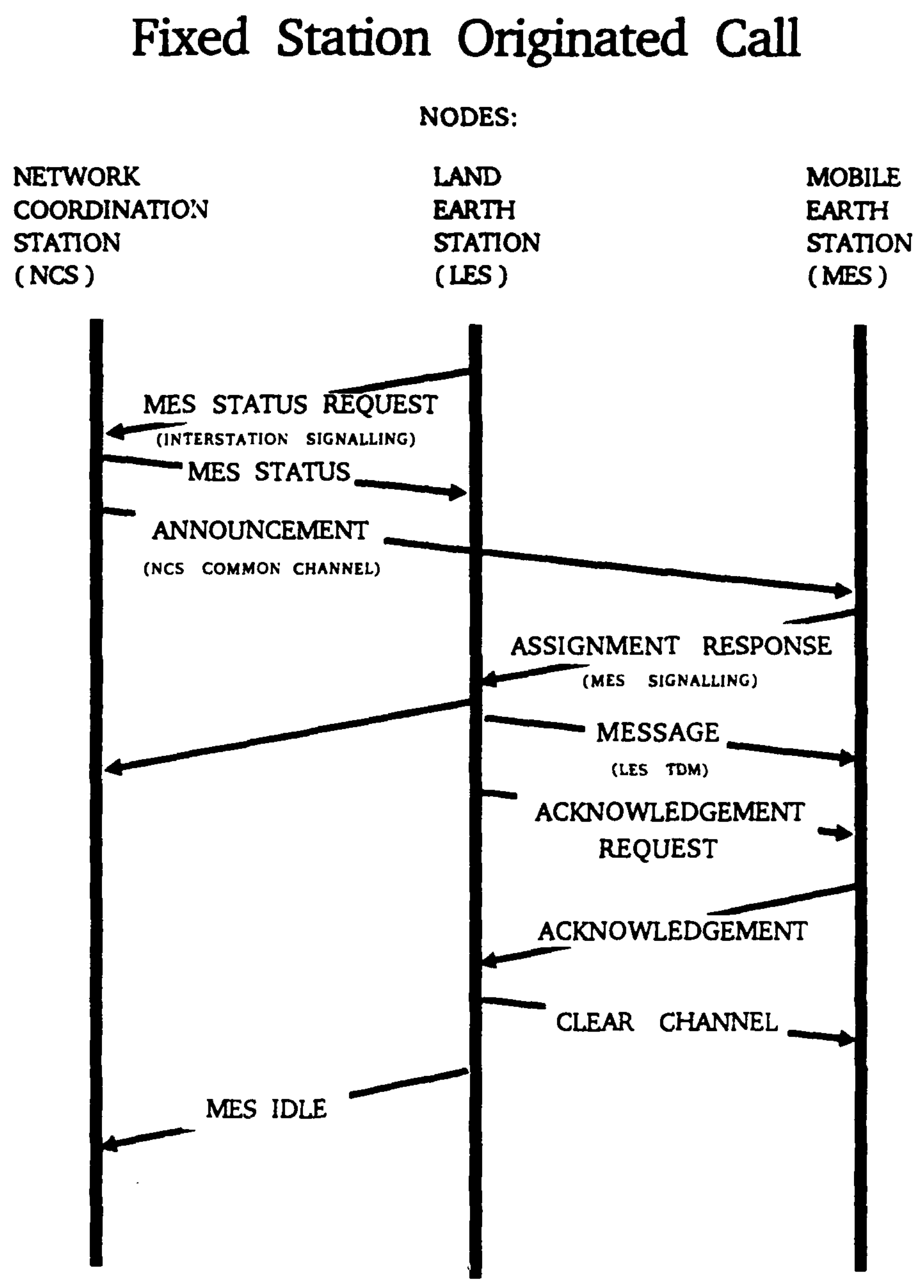

Figure 99. Fixed Station Originated Call

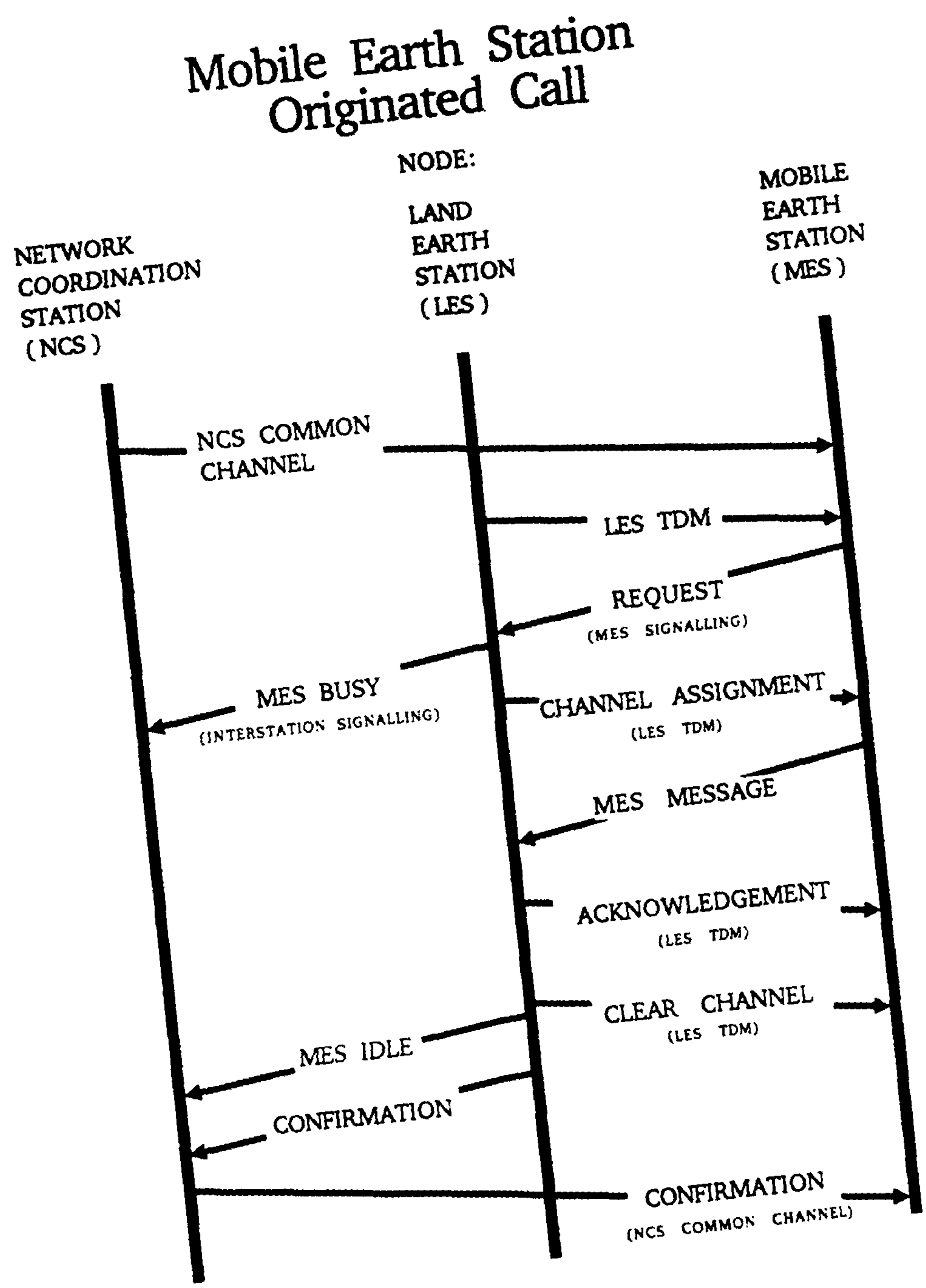

Figure 100. Mobile-Earth Station Originated Call

identification against its list of authorized users. The LES advises the NCS that the mobile terminal is busy and instructs the mobile terminal at what frequency and time to send the message. The message is then transmitted and acknowledged. The LES instructs the mobile terminal to retransmit any packets which were incorrectly received. Upon successful message transfer, the LES instructs the MES to revert to monitoring the NCS. The LES advises the NCS that the MES is idle. [Ref. 84:p. 5]

f. Enhanced Group Calls

Enhanced group calling (EGC) is a message broadcast service which allows single or multiple terminals to be addressed based on a unique individual identification (ID) number, group ID, or geographical area. To receive geographically-addressed messages, the mobile terminal requires a knowledge of its location. This can be automatically obtained from navigation equipment or manually keyed in by an operator. To send an EGC message, a list of terminal identity numbers and the EGC message are sent to a LES. The LES relays the message over the interstation link to the NCS, where it is broadcast to the terminals via the NCS common channel. [Ref. 83:p. 5]

g. Polling

Polling is used to command transmission of a position or data report. Polls can be addressed to individual terminals, groups of terminals, or terminals in a geographic

area. Sending a poll is similar in function to sending a EGC message. [Ref. 83:pp. 4-5]

h. One-Way Automatic Position and Data Reporting

This service enables the terminal to send up to a 32 byte, three-packet position and data report via the MES signalling channel using "unreserved" and "reserved" access methods. Unlike the two-way messaging discussed above, no acknowledgement is sent from the LES. Pricing for this service is lower than the full services described above.

Unreserved access allows the MES to randomly send the first packet of the message into a slot on the MES signaling channel. If a collision occurs, it will be indicated on the LES TDM signaling channel, and the terminal will retransmit. The remaining two packets will be transmitted as per LES direction. Unreserved access is ideal for reporting on an exception basis or when the operating schedule of a vehicle cannot be determined and programmed in advance.

Reserved access transmissions use pre-assigned slots to guarant ◌ reception. The slot assignments are determined by the LES and sent in a poll message which includes the start time, length of assignment, the type of information that should be transmitted, and the duration between transmissions. Reserved access is used when periodic reports are required over time.

No acknowledgement of correct receipt, other than a collision report, is provided for both types of transmissions. The short length of the message and collision detection provide a high probability of accurate reception. [Ref. 83:p. 4]

6. Future Navigation Enhancements

Although INMARSAT was founded primarily for establishing an international maritime mobile communications system, its charter also calls for developing radiodetermination capabilities. Radiodetermination encompasses both passive radionavigation and active radiolocation. These concepts are discussed in Appendix B.

INMARSAT is working to combine GPS, Glonass, and its own satellite system into an integrated communication, navigation, and surveillance (CNS) system. GPS and Glonass both operate on L-band frequencies close to those used by INMARSAT terminals. The addition of a GPS chip set and signal processing software, expected to cost a few hundred dollars in quantity, to an INMARSAT terminal will be less expensive than two separate systems because of the ability to share the antenna, receiver and other common components [Ref. 63]. Position as calculated by the GPS or Glonass receiver will be displayed for the terminal user and can be relayed periodically or on command to the base station.

To provide a "value added" overlay, INMARSAT plans to broadcast differential corrections to improve position

accuracy. Monitor stations can compute and relay differential correction messages to the nearest INMARSAT land-earth station, where they will be broadcast to all users within the region. The mobile terminal in turn will select and pass the correction message to the GPS or Glonass receiver circuitry. [Ref. 86:p. 2]

GPS and Glonass system integrity information can also be relayed. This will enable users to be told almost immediately if there is a problem with either system. The use of INMARSAT satellites to relay navigation signals similar or identical in structure to GPS or Glonass provides another means of positioning, which can strengthen navigation geometry and help reduce user reliance on these national military systems [Ref. 86:p. 4]. GPS and Glonass are discussed in more detail in Appendix B.

7. <u>System Issues</u>

Unlike other single-hub, single-region systems, INMARSAT-C has the advantage of being part of a worldwide communications network capable of providing service to regional, national, and closed user groups. Global coverage, uniform operating standards, and the potential worldwide maritime and land mobile markets will create production economies of scale for terminal manufacturers. The sharing of common functions (such as administrative, network, control and space segments) with INMARSAT-A and aeronautical users distributes fixed and variable operating expenses. These

features, combined with competition between terminal manufacturers and land-earth stations, can reduce total communication costs for all system users.

The global nature of the INMARSAT system allows developing nations to take advantage of communication technology which on a regional or national basis would not be affordable. These countries typically do not have well-developed domestic telephone and other communications systems, particularly outside the major cities. As a result, organizational and economic efficiencies are more difficult to achieve. The use of inexpensive INMARSAT-C terminals to provide mobile and fixed non-voice messaging services is expected to be very cost effective and have a positive impact on the economies of developing nations. [Ref. 67:pp. 230-248]

In theory, the global coverage of the INMARSAT system allows a user to be in constant satellite communications anywhere on the Earth between roughly 80 degrees North and 80 degrees South latitude. Although INMARSAT has mastered the technical aspects of worldwide mobile satellite communications, regulatory hurdles stand in the way of universal use on and above land areas. This is because radio transmission and reception within national boundaries is subject to domestic jurisdiction. For various economic and political reasons, some national telecommunications administrations have acted in their own perceived interests when INMARSAT is capable of providing competitive services. For example, to shield U.S.

mobile satellite service providers, the FCC has prohibited the use of INMARSAT for both domestic aircraft flights (origin and destination within the U.S.) and land mobile services. At the same time, domestic service providers are authorized to compete with INMARSAT where coverage areas overlap outside of the U.S. [Ref. 72:p. 20]. In other instances, various governments have subsidized the cost of lower quality maritime HF radiotelephone and teletype services to promote their continued use [Ref. 87]. In geographic areas where there are many countries, such as in Western and Eastern Europe, the respective domestic regulatory agencies must approve transborder operations or the utility of land-mobile satellite services will be limited [Ref. 63:p. 10]. These types of regulatory restrictions reduce the benefits of satellite communications and limit INMARSAT'S potential revenues.

INMARSAT-C, like other mobile satellite services, also faces the revenue challenge posed by nationwide paging, cellular telephone, and other alternative systems. With its broader market base (land, sea, and air), INMARSAT is probably less affected by alternative terrestrial communication systems than are other satellite providers which primarily service the land mobile market. INMARSAT's view is that cellular telephone and other terrestrial systems complement, rather than compete with mobile satellite systems [Ref. 87:p. 5].

In the aeronautical and maritime areas, INMARSAT provides a higher quality service and is easier to use than

alternative forms of HF communications. The use of INMARSAT by these market segments will increase as existing HF equipment ages, the requirements for merchant marine radio officers are relaxed, and satellite tariffs and equipment continue to fall in price. The ability to provide entirely new services, such as aeronautical passenger voice communications, will also increase demand. Creating a value-added communication, navigation, and surveillance service (CNS) by incorporating GPS and Glonass with INMARSAT will further stimulate demand in all three market segments. As a result, there is no doubt that the service requirement placed on the INMARSAT system will continue to increase.

C. GEOSTAR

In 1982, Dr. Gerard K. O'Neill patented a satellite air traffic control and collision-avoidance system. This system was named the "Triad" because of its reliance on a three satellite triangulation system. Because of FAA reluctance to utilize his invention, O'Neill formed the Geostar Corporation in 1983 [Ref. 8:p. 20]. On 31 March of that year several applications were filed with the Federal Communications Commission (FCC) for the authority to construct, launch, and operate four satellites in the radiodetermination satellite service (RDSS). The regulatory history of RDSS is discussed in Chapter VI.

Geostar has been responsible for much of the interest in satellite communications for long-haul trucking. Geostar has taken an evolutionary approach to implementing RDSS. Each of Geostar's systems is discussed below.

1. System 1.0

Geostar established 1.0 in May 1987 to demonstrate and prove the concept of tracking vehicles by satellite. System 1.0 is no longer operational.

a. System Configuration

The system used Argos transmitters installed on up to 250 trucks. Argos receiver packages located on NOAA/Tiros-N satellites record ground transmitter signals for later replay when within range of a tracking station. Position is calculated by measuring the transmitters' doppler shifts. As configured, data communication was limited to sensor temperature. Position information and temperature data were relayed to Geostar which in turn passed it on to participating trucking firms.[3]

b. System Strengths and Limitations

System 1.0 was relatively inexpensive to implement since the Argos service already existed. The low orbiting NOAA/Tiros-N satellites do not provide continuous tracking coverage. On the average, Argos position fixes occur five to seven times a day, with a maximum of 12 per day. There is

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[3]Interview between Ms. Joann Devincent, Geostar Corp., and the author, April 1988.

also a several hour time lag between the satellite observation and the receipt of position by the end user. The inability to communicate anything but sensor data was also a limitation.

c. Demonstration Results

System 1.0 demonstrated that commercial vehicle tracking was a viable concept. Although position reporting was infrequent, dispatchers were able to tell if drivers were following their assigned routes. An Argos-equipped truck was stolen in Southern California and later found by satellite tracking. One insurance company reduced premiums by almost $100,000 because of satellite coverage [Ref. 88].

2. <u>System 2.0</u>

The desire to create a user base at an early date and at a low financial cost led Geostar to request the FCC's authorization for an interim one-way position reporting and communication relay service. Geostar System 2.0 is not as technically complex or as expensive to implement as RDSS-based on satellite ranging. System 2.0 provides one-way service from the mobile user to the Geostar NMF. This system has the advantage of providing a useful service before the full implementation of RDSS and it generates cash flows for Geostar to invest in the system. Capacity of the system is estimated to be up to one million users [Ref. 89].

a. System Configuration

(1) <u>Mobile Terminals</u>. Sony and Hughes Network Systems manufacture the mobile user terminals. A basic

terminal consists of one antenna and an integrated transmitter, digital processor-coder, and Loran-C receiver. The integrated electronics unit does not require user access and can be mounted anywhere in the vehicle. Peripherals such as a keyboard-display unit and remote sensors can be attached. The cost of the Sony and Hughes terminals are around $3300.[4]

(2) Space Segment. The System 2.0 design uses L-band receiver packages which are integrated with host geosynchronous communication satellites. The combined weight of the L-band antenna and electronics is approximately 15.4 Kg (34 lbs), and average power consumption is only ten watts. The Ku-band downlink to the Geostar NMF uses the host satellite subsystems. [Ref. 90:p. 8]

The first System 2.0 relay package was launched aboard the GTE GSTAR II satellite in the spring of 1986, and failed after a brief period of operation. Analysis revealed the probable cause of failure [Ref. 91]. The design was modified, and a second receive package was lifted in the Spring of 1988 aboard the GTE Spacenet III satellite. This satellite is now stationed at approximately 87 degrees West longitude. A third receive package was launched in September 1988 aboard the GSTAR 3 satellite. This satellite did not achieve the correct orbit, and a program of attitude-control thruster firings was carried out to slowly move the satellite

[4]Interview between Ms. Joann Devincent, Geostar Corp., and the author, April 1988.

to geostationary altitude. The use of station-keeping fuel to move the satellite has reduced its operational life to an estimated three to four years. The GSTAR 3 satellite is located at 93 degrees West longitude, and drifts a few degrees to the north and south of the equatorial plane. The FCC has permitted operation of the satellite providing it wanders no more than five degrees from its assigned location [Ref. 92]. Coverage areas for these satellites include the USA, Southern Canada, and Northern Mexico.

(3) Ground Segment. The Geostar network management facility (NMF) is located in Washington, D.C. Fully redundant equipment is provided to ensure reliability. The NMF contains a Ku-band earth station, return link (mobile to base) processors, and computer equipment. Redundancy is provided through multiple systems.

b. System Operation

(1) User Terminal Operation. Terminal identification, location, sensor data and user messages are randomly transmitted via spread-spectrum burst. Transmissions can be automatically sent based on preset time periods or on terminal user command. Each burst is transmitted at least twice and spaced a few minutes apart to ensure reception. The period between bursts, the number of redundant bursts, and the burst length can be varied. Transmission characteristics are listed in Table 25.

TABLE 25

GEOSTAR SYSTEM II TRANSMISSION CHARACTERISTICS [Ref. 90:p. 4]

Uplink center frequency	1618.25 MHz
Transmission Bandwidth	16.50 MHz
Information rate	15.625 Kb/s
Chip rate	8.0 Mb/s
Modulation	BPSK
Pseudo-random noise sequence	Gold Codes
Burst length	20-80 msec
Maximum characters per message	97
Transmit antenna	Omni-directional
Transmitter power	50 Watts

(2) Space Segment. The spread-spectrum bursts are received by the satellite and amplified. The signals are translated up to a center frequency of 11,801.25 MHz, and retransmitted to the Geostar NMF over one of the communication satellite's regular Ku-band downlink channels. [Ref. 90:p. 7]

(3) Geostar NMF. The Ku band downlink signals are received and converted to a 72 MHz intermediate frequency. The signals are sent through equipment where the spread-spectrum transmissions are acquired, demodulated, and decoded. Multiple demodulators are used to enable the decoding of overlapping spread-spectrum signals.

The decoded messages are routed to the computation center, where the computer equipment provides a

variety of services, such as checking for errors, removing redundant messages, time stamping, converting to a user desired format, and performing priority and emergency flagging. The messages are stored in an "electronic mailbox" pending auto-dial up by the users computer or are sent in almost real-time over the user's dedicated communication link. [Ref. 90:pp. 9-12]

c. System Strengths and Limitations

The light-weight and low-power requirements of the L-band receiver package enable it to be placed aboard a host satellite for only a portion of the cost of construction, launch, and operation of a dedicated satellite. This enables initial systems to be implemented with a minimum of financial and technical risk. Two manufacturers with solid reputations produce and support the user terminals.

As discussed in Appendix B, when Loran-C receivers are used in the "mid-continent gap," their positioning information will be degraded. This coverage gap will be eliminated by the end of 1990 when the mid-continent expansion project is completed.

The major limitation of System 2.0 is its one-way nature. Dispatchers can track their vehicles and receive inbound messages, but they cannot contact their drivers. Because no acknowledgement of message receipt is possible, the system cannot advise users when their messages are not delivered. However, the probability of the NMF correctly

receiving the message is increased by programming the mobile terminal to repeat each transmission several times. These limitations require most users to occasionally check in with the dispatcher via telephone or use a nationwide paging service.

3. Geostar System 2C

a. Description

Geostar introduced 2C service in the Summer of 1989 to enable two-way mobile communications. Inbound communication between the mobile unit and the NMF uses the System 2.0 service described above. Outbound messages from the user control point are sent to the Geostar NMF, where they are sorted and time division multiplexed into a 1200 bit per-second data stream. To maximize throughput, message length is variable up to 128 characters. The data stream is routed to GTE's satellite earth station facility in Woodbine, Maryland. At this location it is direct sequence binary phase-shift keyed with a pseudorandom noise code at a 1.2288 MHz spread-spectrum chip rate. The resulting outbound signal is relayed by the GTE Spacenet III satellite. Both the uplink and downlink are within the C-band. [Ref. 6]

The outbound downlink has a capacity of approximately 10,800 messages per hour, assuming an average address and message size of 50 characters.[5] Additional

[5]Telephone conversation between Mr. Nick Cheston, Geostar Corp., and the author, 26 April 1989.

transponders can be leased to increase the capacity of the system. The FCC has authorized Geostar to operate up to 20,000 units [Ref. 6].

System logic provided for message acknowledgements over the outbound path. In the event an acknowledgement is not received, the mobile transceiver or NMF will retransmit as necessary.

The Sony and Hughes equipment used for System 2.0 is also used in the 2C upgrades. For Hughes, the System 2.0 antenna is replaced with an integrated omni-directional antenna unit (Loran-C, L-band, and C-band). A receiver is connected to the new antenna and to the existing integrated transmitter. With Sony equipment, the transmit antenna is replaced with an integrated omni-directional L-band and C-band antenna. A receiver is added and interfaced to the transmit unit.[6]

b. System Strengths and Limitations

The C-band is also used for terrestrial microwave transmission, and the omni-directional antenna is subject to interference. However, the choice of operating frequency within the C-band minimizes this problem.[7] Also, a degree of protection is provided by the spread-spectrum modulation and

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[6]Telephone conversation between Mr. Nick Cheston, Geostar Corp., and the author, 26 April 1989.

[7]Telephone conversation between Mr. Paul Pecka, Sony Corp., and the author, 26 April 1989.

processing gain. The 1200 bit per second downlink is 13 times slower than the mobile transmitter uplink, and is a limiting factor to total system throughput. However, most of the information flowing through the system is inbound from the mobile terminal (hourly position updates, load status messages, etc) to the NMF, so this difference is not as severe as it appears. A Geostar official estimated that 75% of the total message volume will be inbound to the NMF, with only 25% of the messages flowing through the outbound path.[8]

4. Geostar System 3.0

Geostar System 3.0 is the configuration envisioned in international frequency allocations and the FCC RDSS license. Its spread-spectrum signal structure allows multiple RDSS systems and satellites to use the same frequencies with minimal interference. This permits millions of users to be served at a very low cost per unit. The system also provides the ability to determine transceiver position without using an external radionavigation system. Location accuracy is between 20 and 50 meters, and can be refined to fewer than ten meters through differential correction [Ref. 8:pp. 37-58]. Implementation is scheduled to begin the last quarter of 1993 [Ref: 93].

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[8]Telephone conversation between Mr. Nick Cheston, Geostar Corp., and the author, 26 April 1989.

a. System Configuration

Figure 101 illustrates the general configuration of Geostar System 3.0. The design and operation of System 3.0 is more complicated than its predecessors because it uses a combination of spread-spectrum and time-division multiple access (TDMA), two or more satellites for ranging, and a network of benchmark transceivers. Readers not familiar with spread-spectrum modulation, TDMA, and satellite ranging should consult Appendix B.

(1) User Terminals. User terminals will be similar to the existing L-band Sony and Hughes System 2.0 and 2C equipment, except for the downlink antenna, receiver, and processor sections. The terminal will be configured to receive the 16.5 MHz wide S-band spread spectrum transmissions centered on 2491.75 MHz, and the receive processor is designed for the new downlink format and increased transmission speed.

Figure 102 is a generic block diagram of a System 3.0 terminal. The transceiver consists of a baseband processor, a spread-spectrum modulator and demodulator (modem), and a receive and transmit chain. The baseband processor (BBP) controls and monitors the overall operation of the terminal and is the interface through which all inputs and outputs pass. [Ref. 8:p. 91]

Like System 2C transceivers, System 3.0 terminals have unique electronic identification codes and group call functions. The terminals can be programmed to

Geostar System 3.0 Configuration

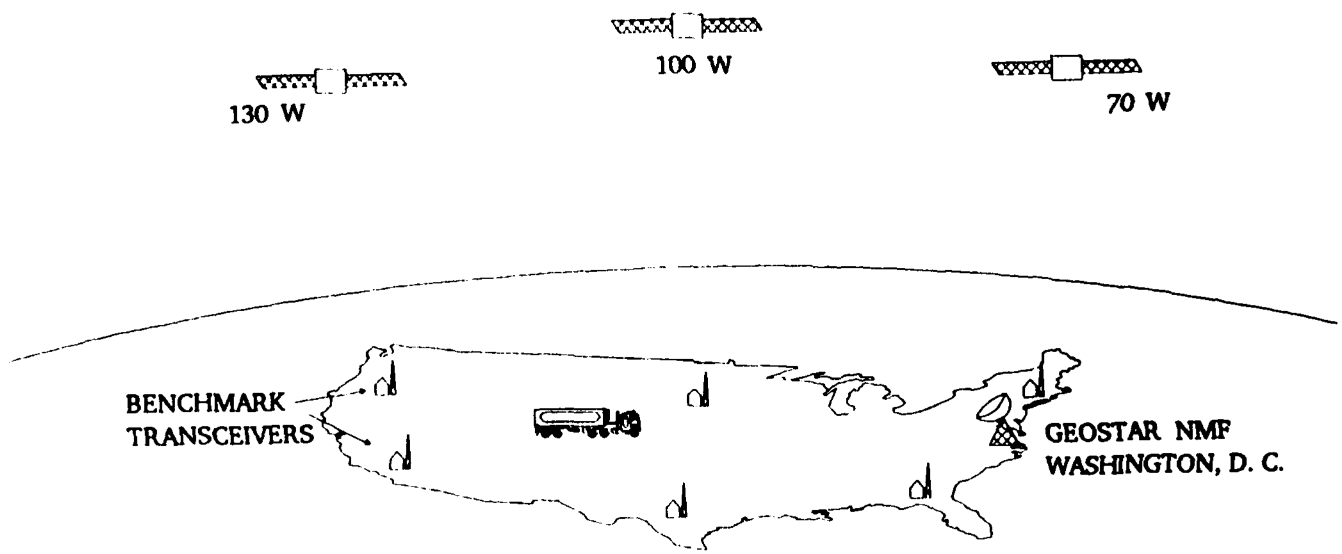

Figure 101. Geostar System 3.0 Configuration

Geostar System 3.0
Standard Transceiver Block Configuration

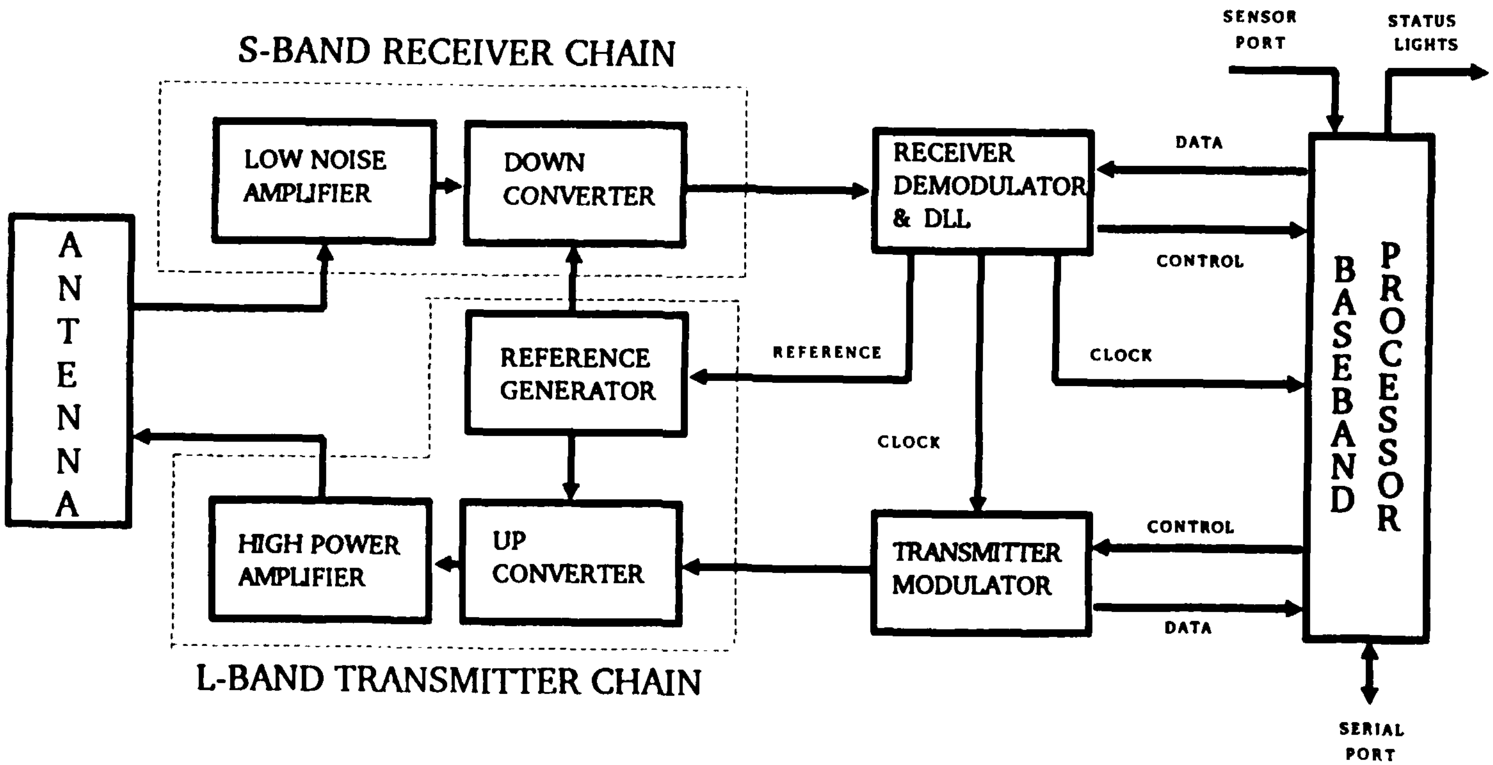

Figure 102. Geostar System 3.0 Standard Transceiver Block Configuration

automatically transmit at specific intervals, and can be polled for position and data reporting. [Ref. 8:p. 99]

(2) Space Segment. The System 3.0 design is capable of functioning with a minimum of two dedicated RDSS satellites, but a third satellite is required for redundancy and to satisfy license requirements. These satellites will be placed in geostationary orbit about 30 degrees apart over the U.S. and will use up to eight spot beams to maximize communications capacity [Ref. 8:p 69]. The first generation System 3.0 satellites will use single beams on the forward and return links [Ref. 93].

Instead of acting like a "bent pipe" on the C-band forward uplink, second generation multi-beam satellites will contain a receive processor, message router, and PRN generator. The receive processor demodulates the uplink signal, and the router directs the information to the appropriate spot beam processor. The same PRN code is used in each downlink spot beam processor. To isolate the geographically overlapping S-band spot beams, each spot beam processor will delay the transmission of its messages by a different increment of time.

On the return link, up to eight spot beam signals are "bent piped" into one of the four 16.5 MHz-wide sub-bands within the 66 MHz wide C-band downlink. The two return links retransmitted within each of these sub-bands are separated by opposite polarization. [Ref. 8:pp. 69-73]

(3) Network Management Facility. All communication and position determination will take place through the Geostar NMF. The NMF contains the C-band earth stations for transmitting the 16.5 MHz wide uplink (6.525 GHz to 6.5415 GHz) and receiving the 66 MHz wide downlink (5.150 GHz to 5.2160 GHz). Multiple forward and return link processors are used to maximize throughput. Network management computers are used to calculate position; assemble, store, retrieve, and route messages; and do other administrative functions such as customer billing. All NMF components will be redundant. Aside from position determination, the function and interconnection of the NMF to terrestrial communication networks is similar to the Geostar 2C system. [Ref. 8:pp. 75-89]

(4) Benchmark Transceivers. A number of benchmark transceivers will be widely dispersed throughout the coverage area at precisely surveyed locations. These transceivers are used to accurately determine each satellite's position in geostationary orbit. These same transceivers can also be used to provide differential corrections to refine the position solution. [Ref. 8:pp. 83-84]

b. Geostar System 3.0 Multiple Access Architecture

(1) Spread Spectrum. Spread-spectrum modulation was chosen to enable many simultaneous RDSS user transmissions, provide an adequate link margin for low gain omnidirectional antennas and low power transmissions, and to permit

accurate ranging. The eight MHz pseudorandom noise (PRN) spreading rate was selected to strike a balance between the necessary processing gain, desired ranging accuracy, and the available RF spectrum.

Multiple PRN sequences allow spread-spectrum transmissions to take place simultaneously on the same frequency without interfering with each other. To do this requires a separate receive processor and knowledge of the PRN code for each spreading sequence. Multiple transmissions with the same PRN code can also overlap each other on the same frequency as long as they are all slightly offset in time. In this case, there must be a way to assign individual signals to a separate receive processor for recovery. The later technique is used in System 3.0.

Identical time-shifted PRN sequences are used to isolate the forward downlink spot beams on second generation RDSS satellites. Beam selection and tracking is based on signal strength. Multiple processors are used in the NMF to enable reception of overlapping user terminal messages.

The eight MHz PRN code rate used on the forward and return link produces a signal bandwidth of 16 MHz. The forward link is broadcast at approximately 125 kbps, which uses 64 PRN chips per bit. This gives the forward link a spread-spectrum processing gain of 18 dB. Return link transmissions take place at approximately 16 kbps, which uses 512 PRN chips per bit and produces a processing gain of 27 dB.

These processing gains provide the link margin required for the system to reliably function [Ref. 8:pp. 33-35]. The eight MHz PRN code produces a single chip range resolution of approximately 37.5 meters or 123 feet. This accuracy is substantially improved by measuring the round trip transit time to a fraction of a chip [Ref. 8:p. 42].

(2) Time Division Multiple Access (TDMA). TDMA separates messages by permitting their transmission only within a specified block of time. Precision network timing signals can also be used as a reference for satellite ranging.

Each major division of time on the forward link, called a superframe, lasts approximately 1073.73 seconds or 17.9 minutes. Within each superframe are 65,536 sequentially numbered frames. This equates to a frame length of 0.0164 seconds (16.4 ms), or about 61 frames per second. Each frame contains 1024 bits. The frame begins with a spread-spectrum acquisition aid sequence followed by its frame number, satellite downlink beam number, and data packets addressed to one or more users. Data packets contain messages and other information, such as cyclic redundancy check (CRC) codes used to determine whether the message was correctly received. This time and packet data structure is broadcast sequentially at a rate of 125 kbps over the outbound link and is received sequentially by each terminal within the coverage area. [Ref. 8:pp. 75-76]

Inbound link data are transmitted at one-eighth of the forward link speed or 16 kpbs. In contrast to the outbound link, inbound link frames are variable in size from 240 to 1024 bits, which equates to a transmission time of 15.4 ms to 65.6 ms. The actual message data portion can occupy up to 912 bits. The remaining 112 bits are used for spread-spectrum acquisition, to record the outbound frame number to which the inbound frame is synchronized, for addressing, and for message routing and transceiver status. [Ref. 8:p. 76]

Unlike the forward link, where messages arriving from terrestrial networks at the NMC are queued and transmitted one after another in serial fashion, randomly generated terminal messages are temporarily held in memory and transmitted on receipt of the <u>next</u> forward link frame timing signal. This time synchronized random-access entry is termed slotted ALOHA.

When used with conventional modulation, a slotted ALOHA channel can carry up to 36% of its theoretical data capacity. This is because randomly transmitted messages which are synchronized to the same frame will "collide" with each other and be improperly received by the NMC. Each station will then have to retransmit, thus reducing the total capacity of the uplink. However, with spread-spectrum modulation the channel capacity is raised to above 60%. This is because each terminal is a different distance from the

satellite (assuming they are not located on the same range circle) and each will receive the downlink frames at a slightly different time. Although the return link transmissions will still overlap, there is a high probability their identical spreading sequences will be offset by more than a few PRN chips. This prevents the messages from "colliding" as would occur with conventional modulation, and allows the overlapping messages to be recovered at the NMF by using multiple return link receivers and processors. [Ref. 8: pp. 121-122]

c. System Operation

Figure 103 illustrates the basics of System 3.0 operation. The NMF continuously broadcasts precision timing information as part of the outbound frame format. The outbound frames contain sequential packet messages addressed to particular terminals. Terminals transmit in synchronization with the outbound frames, and the signals are relayed via two or three satellites to the NMF. The NMF decodes the message and calculates the terminal's geographic position by measuring the signal arrival times. Acknowledgement logic ensures all messages sent from the NMF and mobile terminals are received. Retransmissions will automatically take place if an expected reply is not received within a certain interval. [Ref 8:p. 90]

(1) Forward Link. Figure 104 illustrates the operation of the forward link.

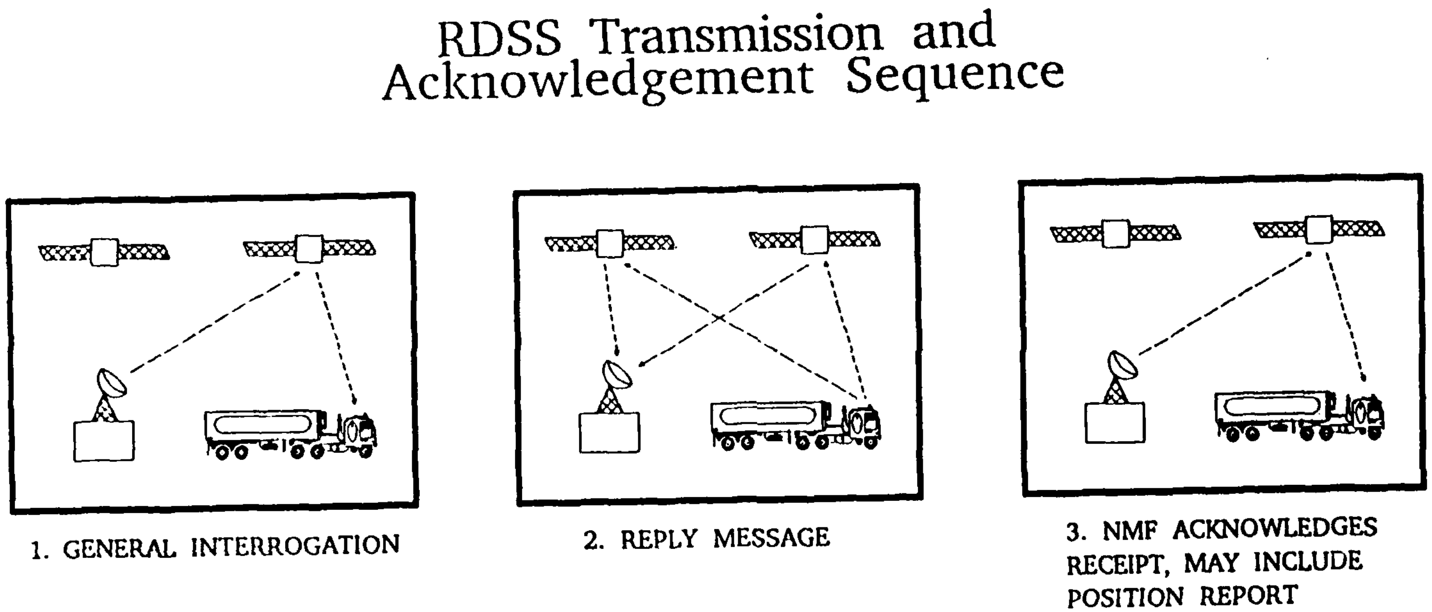

Figure 103. RDSS Transmission and Acknowledgement Sequence

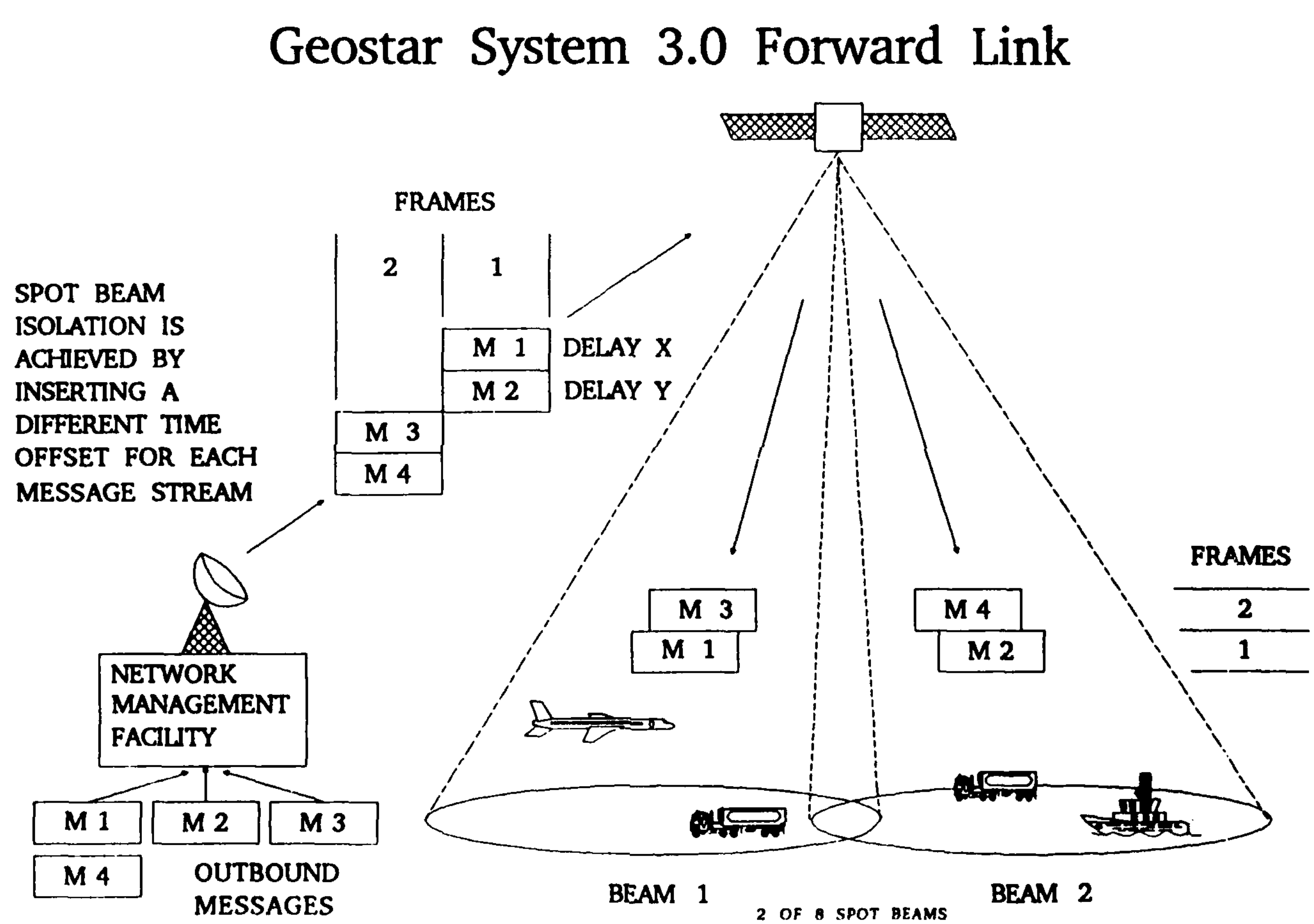

Figure 104. Geostar System 3.0 Forward Link

Fixed users or "base stations" send messages, position inquiries, control signals, and other data via terrestrial and satellite communication links to the NMF for relay. The NMF computers validate sender and terminal identification and assign a beam number based on the terminal's last known location. The messages are assembled into packets and convolutionally encoded for forward error correction (FEC). FEC adds about 5.2 dB gain (equivalent to a 3.3 times increase in signal strength) by enabling random bit errors to be corrected in the terminal's receiver. The NMF computers then place outbound messages in a queue for transmission on the forward link based on time of arrival and priority. [Ref. 8:pp. 79-82]

A single satellite receives the network management center's uplink signal. Depending on anticipated message loading, the satellite can be configured with up to eight spot beams. Spread-spectrum message streams, each one addressed to a different spot beam, are transmitted on the 16.5 MHz wide uplink. Each message stream has a different time offset. The data packets are received, decoded, and routed to the appropriate spot beam transmitting sections. Using the <u>same</u> PRN code for all spot beams, the data are again spread-spectrum modulated and transmitted on the downlink.

The timing offsets inserted by the NMF allow the terminals to discriminate between the beams.[9]

Unless transmitting, all terminals continuously monitor the downlink. The received S-band signals are down-converted and routed to the delay-locked loop (DLL) and demodulator circuitry, where the spread-spectrum signal is acquired, tracked, synchronized, and decoded. The preamble provides the initial signals for starting the receiver's clock and synchronizing the PRN generator to allow demodulating the BPSK signal. A frame-timing mark is also sent to the baseband processor to control the start of any pending transmission. The recovered packet is routed through the decoder, where forward error correction (FEC) is performed to correct any bit errors. The signal is then sent to the baseband processor, where the message is recovered. Messages not addressed to the terminal are discarded. If the message is addressed to the terminal, the baseband processor routes it to the appropriate input/output port for equipment command or operator display. This process repeats itself with the receipt of each new frame and packet. [Ref. 8:pp. 96-99]

The terminal's geographic position determines which spot beam will be used for reception. When turned on for the first time, the terminal will enter an acquisition mode. To acquire the proper beam, the terminal will search

[9]Information regarding timing offsets was provided by Geostar during their review of the draft thesis.

for the spread-spectrum sequence with the strongest signal. Since interference will be encountered within areas where beams overlap, a high degree of signal level and tracking sensitivity are required. Automatic changeover from one beam to another will take place when the new signal reaches sufficient strength.[10]

(2) Return Link. Figure 105 illustrates the return link.

When a message or position report is to be transmitted, the data are formatted by the baseband processor (BBP) and held temporarily in memory. The BBP inhibit counter is set, and when the next frame number is received on the downlink, the counter goes to zero. When this occurs, the current frame number the terminal is receiving is incorporated into the data packet. This frame number is used by the NMF computers to resolve ranging ambiguity. The packet is then sent through a convolutional encoder, which provides FEC to enable the NMF to detect and correct bit errors. The output of the encoder is then combined with an acquisition code and PRN sequence, and subsequently routed to the BPSK modulator. The resulting signal is up-converted, sent through a power amplifier, and transmitted. [Ref. 8:pp. 99-102]

The geographically dispersed benchmark transceivers act in the same manner as the user terminals.

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[10]Information regarding timing offsets was provided by Geostar during their review of the draft thesis.

Geostar System 3.0 Return Link

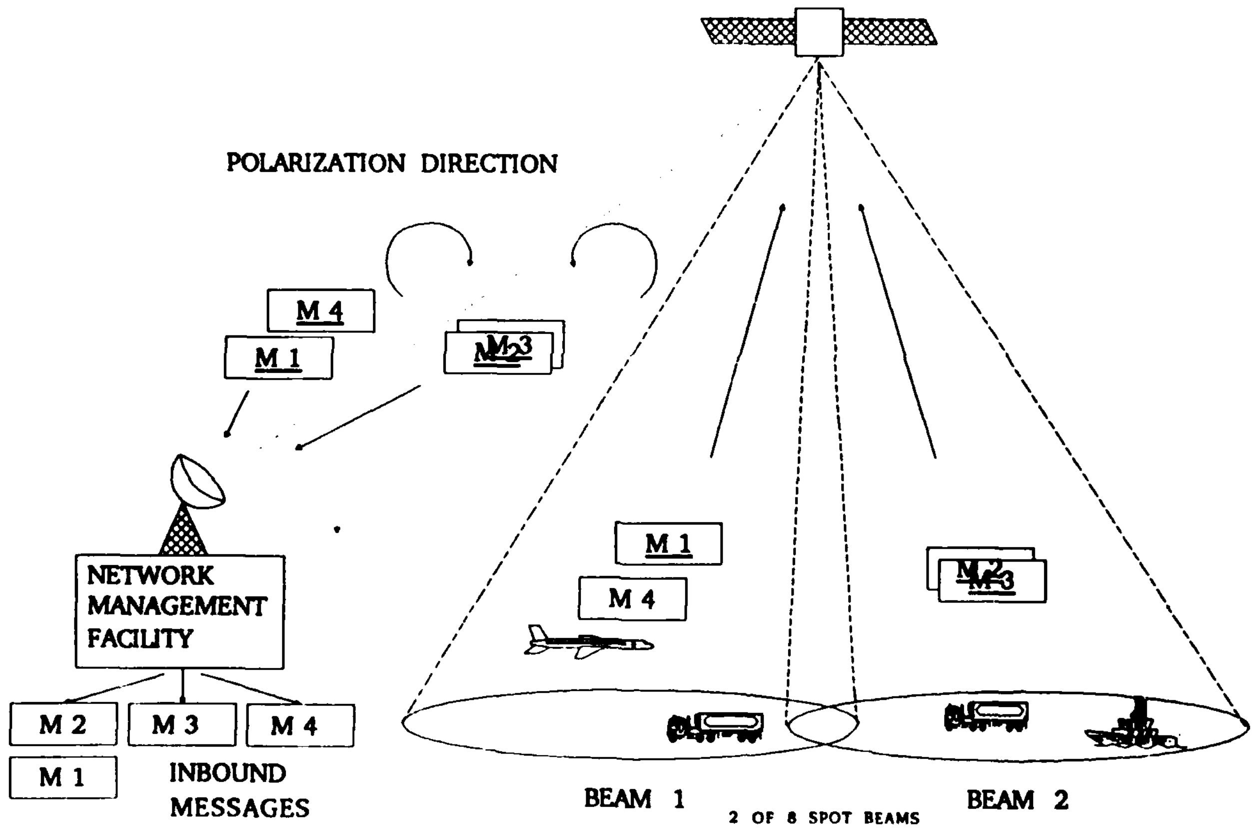

Figure 105. Geostar System 3.0 Return Link

They burst a reply signal at certain intervals or on NMC command.

The satellite acts as a "bent pipe" on the return link. Up to eight spot beam signals are frequency translated onto four 16 MHz downlink sub-bands. The two return link signals which share a common downlink frequency are separated by routing them through transmit antennas which have different polarizations. [Ref. 8:p. 70]

At the NMF, the return spread-spectrum downlink signals are received, detected, and acquired. Once PRN synchronization and tracking is achieved, the data are demodulated and the packets are sent through a Viterbi decoder. This circuit uses the signal's forward error correction to recover random bit errors. The messages are retrieved, and the terminal's location is computed by measuring the arrival time of signals relayed by two or more satellites. The message is then routed to an electronic mailbox pending user connection with the NMF, or is sent in almost real-time over the user's dedicated communication link.

(3) Position Determination. Position determination is a more complicated process than suggested above and requires some additional explanation. Figure 106 conceptually illustrates how the terminal's location is computed based on the arrival times of two or more return signals.

As discussed above, the basic unit of time within the system is the superframe, which is subdivided into

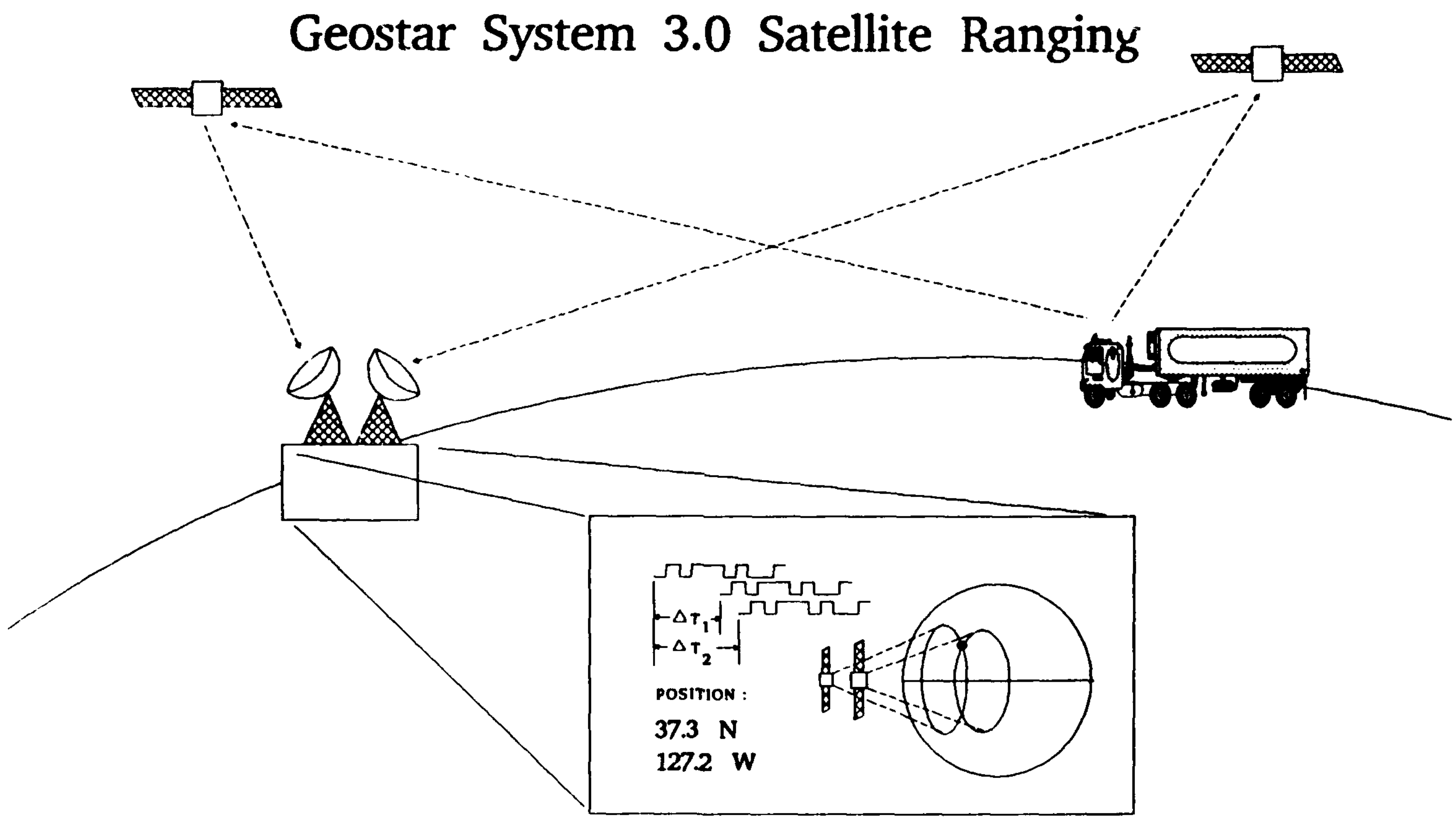

Figure 106. Geostar System 3.0 Satellite Ranging

65,536 frames which are 16.4 ms long. This frame duration is determined by the length of the repeating PRN code and the speed at which it is sent. The basic unit of time within each frame is the length of the PRN chip. Time can be further resolved by measuring the fraction, or phase, of a single chip against a reference chip. Therefore, system elapsed time is composed of the number of frame repetitions, plus the number of PRN chips elapsed since the start of the current frame, plus the instantaneous chip phase.

To determine round-trip transit time, the returned signal must be measured relative to when it was sent. When routed a signal, the receiver's PRN generator will synchronize to the incoming spread-spectrum sequence by decoding its acquisition preamble. Other receiver circuitry monitors the forward-link frame-timing signals. Very precise time of arrival measurements are made by measuring the number and fraction of PRN code shifts required to align the synchronized receiver PRN code generator with the frame reference mark. However, this method can only measure the number and fraction of chips since the start of the current outbound frame. Since the PRN sequence repeats itself every 16.4 ms, this produces a range ambiguity of about 4920 kilometers or 3050 miles.

Recall that each terminal's transmission contains the beam number and forward-link frame number the terminal was receiving when its transmission began. To

resolve the range ambiguity, coarse time is determined by recovering the outbound frame number and subtracting it from the number of the frame currently being transmitted by the NMF. The coarse and precision times are added together to produce the total round-trip transit time.

As illustrated in Figure 107, benchmark transceivers are used to determine the position of each satellite in orbit. This is possible because the benchmarks are located at precisely surveyed sites, and the satellite positions are treated as unknowns. The calculated satellite positions are periodically updated and stored in a program table. To calculate terminal location, the transit time of two or more signals are mathematically converted to range spheres centered on their respective relay satellite. A digital terrain map or an encoding altimeter produces a third earth sphere by providing the distance from the center of the Earth. An algorithm combines the values for these three spheres to determine where they intersect. This produces an ambiguous North and South solution because the RDSS satellites lie in the same equatorial plane. One solution is discarded since the NMF knows which hemisphere the terminal is located in. System logic is capable of tracking mobile terminals which cross the equator and will automatically change which solution is discarded. [Ref. 8:pp. 83-88]

The accuracy of location calculations is influenced by satellite positioning geometry. Using two

Geostar System 3.0 Positioning Subsystem

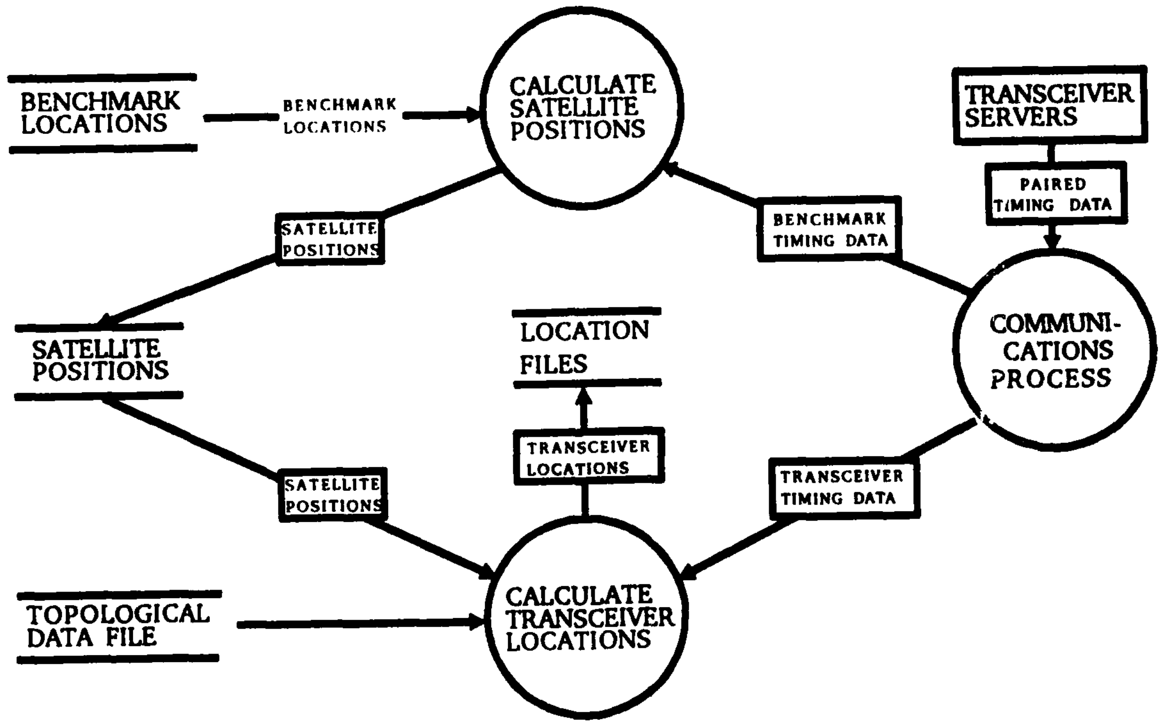

Figure 107. Geostar System 3.0 Positioning Subsystem

Geostar satellites for ranging, combined with a model of the Earth, produces a geometric dilution of precision of between 1.5 and 2.0 in moderate latitudes. This means that a one-meter ranging error results in a 1.5 to 2.0 meter positioning accuracy. [Ref. 8:pp. 39-41]

Besides GDOP, there are many other potential error sources. These can be grouped into the following error categories: satellite, ranging, three-dimension or earth sphere, calibration, and computational. Satellite errors refer to unknowns in orbital position and motion. Ranging errors are caused by erroneous timing, atmospheric effects which slow and bend the transmissions, and multipath signals. Three-dimensional errors are created by inaccuracies in the terrain map data base or altimeter. Calibration errors are due to inaccurate reference locations, variable delays in the equipment, and barometric altimeter corrections. Finally, computational errors are introduced by computer rounding and the algorithms used for position determination [Ref. 8:pp. 37-57]. A more detailed discussion of the nature of these errors is beyond the scope of this thesis.

Some of these errors can be reduced through mathematical modeling. A number of differential correction benchmark transceivers spaced throughout the coverage area can also be used to reduce the effects of errors. Differential correction can be performed in one of two ways. The calculated position of the benchmark transceiver is compared

to its known location, and a correction factor is produced. Conversely, the known range from the satellite can be compared to the calculated range, and a range bias correction determined. These factors are then interpolated between benchmark sites and applied to the positioning solution. This method of correction can reduce positioning errors down to less than 50 meters, dependent on the proximity to the benchmarks. Additional ranging measurements will reduce the solution errors and increase positioning accuracy. [Ref. 8:pp. 40-41]

d. System Issues

By designing a system around the properties of spread spectrum, Geostar System 3.0 is capable of providing communications and positioning services to millions of users with just three satellites (two for positioning and one as spare). System 3.0 add-on packages can be incorporated into geostationary satellites to provide RDSS communications in areas with a lower traffic base. Spread-spectrum transmissions, with a slotted ALOHA efficiency of more than 60%, make greater use of limited spectrum than do single channel per-carrier communications. This large capacity potentially enables users to be served at a very low capital cost per unit. Conversely, at high loading rates System 3.0 can generate very large revenues and be exceptionally profitable. However, at lower levels of use, System 3.0 can be much more

expensive per user because of the number of satellites required to enable position determination.

The use of single-channel, TDMA spread-spectrum avoids the requirement for narrow-band frequency assignment logic, separate signalling frequencies, and associated components in the user terminal and NMF. By computing the user's position centrally at the NMF, the requirement to incorporate a Loran-C or GPS receiver into the terminal is eliminated. As a result, the user receives positioning information for the basic price of communications. These characteristics, combined with the large system capacities, potentially allow user terminals to be mass produced at a very low cost per unit.

D. QUALCOMM OMNITRACS

The OmniTRACS system uses fixed satellite service (FSS) Ku-band (14.0-14.5 GHz uplink, 11.7-12.2 GHz downlink) transponders instead of specialized transponders or satellites dedicated for mobile use. To use these FSS transponders, Qualcomm had to design a system with transmission characteristics similar to existing Ku-band services. Because the OmniTRACS mobile antenna is capable of illuminating more than one Ku-band satellite, the system had to be designed to prevent interference to other Ku-band transmissions. The FCC has authorized Qualcomm to initially operate up to 20,600 mobile terminals on a not to interfere basis with primary and

secondary fixed Ku-band services. Additionally, OmniTRACS users must tolerate any interference from these services [Ref. 7].

1. System Configuration

a. User Terminals

The OmniTRACS mobile terminal consists of three subsections. The outdoor unit contains the antenna and Ku-band transmit and receive electronics. The antenna is steerable in azimuth only and has a vertically-polarized asymmetric radiation pattern of approximately 40 degrees in elevation and six degrees in azimuth. The antenna is fed by a one watt power amplifier and has a gain of 19 dBi (a factor of about 80). The assembly housing is approximately 25 cm (ten in) in diameter, 15 cm (six in) high, and weighs approximately four Kg (nine lbs). The outdoor unit can be roof or mast-mounted.

The communication unit contains the Loran-C receiver and OmniTRACS analog and digital electronics. The communication unit can be mounted anywhere in the vehicle since it does not require operator access.

The display unit contains a 40 character by four line display and an ABCD or QWERTY keyboard. The display unit also provides several keys for pre-programmed user functions. The display contains indicators for message-waiting, satellite synchronization and power indication. The display unit can

also be operated in a maintenance mode for trouble shooting. [Ref. 94:p. 208]

b. Space Segment

The OmniTRACS system uses two protected Ku-band transponders located aboard the GTE Spacenet GSTAR 1 satellite stationed at 103 degrees West longitude. The transponders act as a "bent pipe" for the forward and return transmission links, and cover the continental United States, Northern Mexico, and the southern portion of Canada. Two alternative satellites and transponder pairs can be used if difficulties occur with the primary transponders. Changeover from the primary satellite is automatic.[11]

c. Ground Segment

The OmniTRACS NMF is located in San Diego, Ca. The NMF contains a Ku-band earth station, forward and return link processors, and a network management computer. Each system is fully redundant to ensure reliability.

2. System Operation

a. General

Several methods are used to ensure compatibility with existing Ku-band services. The NMF controls the number and frequency assignment of terminals so that the level of potential interference is always tightly regulated. A mobile

[11]Speech by Dr. Andrew Viterbi, Qualcomm Inc., at the Phillips Publishing Mobile Satellite Conference, Washington, D.C., 6 November 1989.

terminal will not transmit unless commanded to do so by the NMF. Hybrid spread-spectrum modulation techniques are also used to minimize potential interference. This allows the combination of all transmitting user terminals to produce a uniformly spread signal which does not exceed certain specified power limitations. [Ref. 95]

b. User Terminal Operation

Figure 108 shows a block diagram of the user terminal. A 11.7 to 12.2 GHz low-noise amplifier and down-conversion circuit provide signals to the acquisition, tracking, and demodulation circuitry. During transmission an up-conversion circuit provides a signal in the 14-14.5 GHz band to the one watt power amplifier.

The OmniTRACS system uses a steerable directional antenna to prevent interference to the other Ku-band satellites stationed along the orbital arc. The antenna also facilitates mobile transmission and reception by reducing multipath and other interference, and its 19 Dbi gain allows lower transmitter power and receiver sensitivity. The antenna is kept trained on the satellite by circuitry which continually monitors the forward link (NMF to terminal) signal. When the mobile unit is not in receive synchronization, it executes a *receive acquisition* algorithm until data from the satellite can be received and demodulated. At that point the antenna is pointed toward the satellite and messages can be received from the NMF. Mobile transmissions are made

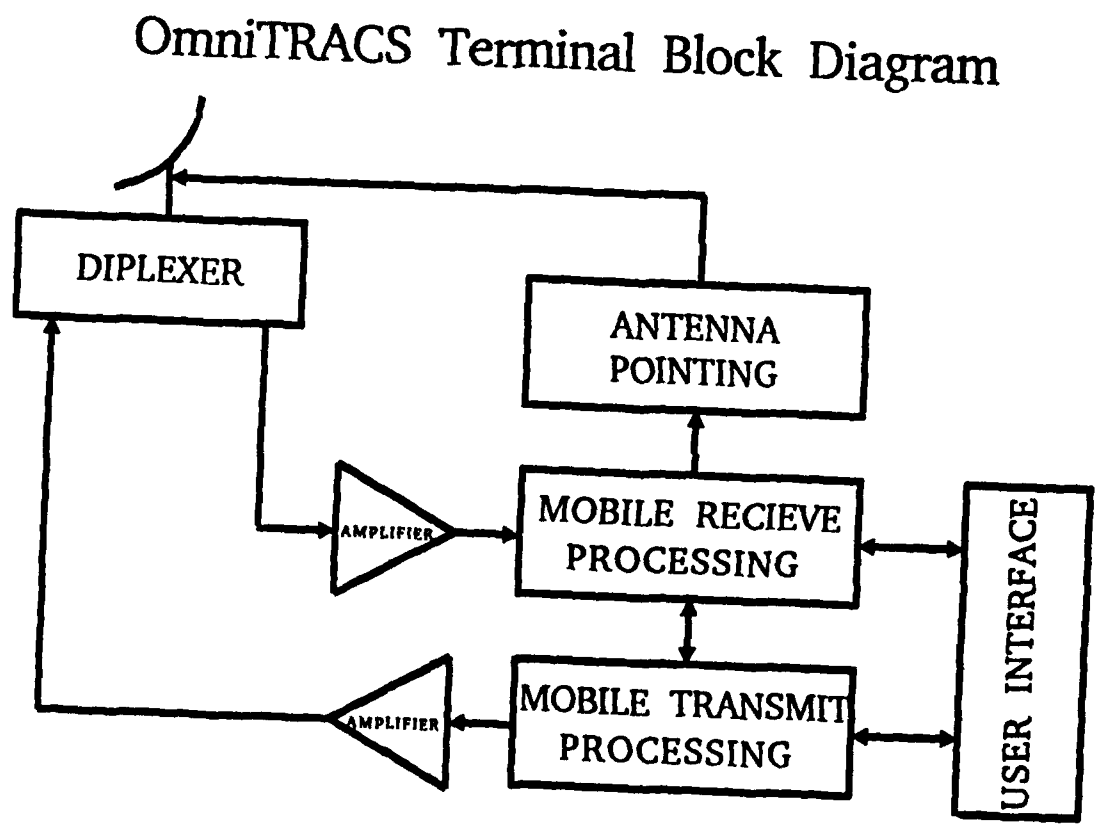

Figure 108. OmniTRACS Terminal Block Diagram

at a 50% duty cycle to allow for continued reception and antenna tracking of the downlink signal. If at any time during a transmission the received downlink is lost, the assumption is made that the antenna is no longer tracking the satellite. When this occurs the terminal will immediately cease transmission to prevent interference to other Ku-band satellites. The antenna will then enter the signal acquisition mode and attempt to relocate the satellite. Upon reacquisition the message will be retransmitted. [Ref. 94:pp. 205-207]

Data from the mobile terminal interface passes through a forward-error correcting (FEC) encoder, is frequency shift-keyed (FSK), and then direct-sequence spread at one million chips per second to produce a signal bandwidth of one MHz. The one MHz signal is frequency-division multiplexed (assigned a frequency range within the allocated spectrum) and frequency hopped over a 48 MHz or less bandwidth. [Ref. 94:p. 206]

Variable data rates are provided to allow for different communication conditions. To maximize system throughput, user terminals experiencing good communication conditions transmit at 132.3 bits per second. User terminals in areas with reduced conditions transmit at 22 bits per second. Up to 250 terminals can transmit at the same time. Messages can be up to 2000 characters long, and are encrypted under the Federal Data Encryption Standard (DES). System

logic incorporates error checking to ensure that all messages are received. If the terminal does not receive a receipt acknowledgement from the NMF, the message is automatically repeated as many times as necessary. Conversely, when the terminal correctly receives a message, it automatically sends an acknowledgement to the NMF. [Ref. 94:p. 206]

Position information is currently derived from the installed Loran-C receiver. The system is capable of incorporating a GPS receiver if more precise location accuracy is required. A satellite ranging system has also been developed.

c. Space Segment

The GSTAR I satellite receives the forward and return uplink signals, amplifies and frequency translates them, and rebroadcasts them on the downlink.

d. OmniTRACS NMF

Forward-link binary data are encoded and used to drive a binary phase-shift keying (BPSK) modulator. The data rate is variable between five and 15 Kbps. Most of the U.S. is covered by the 15 Kbps signal, while a five Kbps rate is used for units in the Southwest.[12] The variable rate signal is then modulated by a triangle-wave dispersal waveform over two MHz of the transponder passband. The interference of this

[12]Speech by Dr. Andrew Viterbi, Qualcomm Inc., at the Phillips Publishing Mobile Satellite Conference, Washington, D.C., 6 November 1989.

signal is less than that of a typical Ku-band video carrier and makes coordination of frequency easier [Ref 94:pp. 207-208].

NMF system logic for ensuring message receipt and delivery is identical to the function of the terminal described above. Messages from mobile terminals are stored in an "electronic mailbox" pending auto-dial-up by the users computer or can be sent in almost real-time over the user's dedicated communication link.

3. System Capacity

Based on message loading, the capacity of the OmniTRACS system is between 40,000 and 60,000 units per transponder pair.[13]

4. System Enhancements and Future Developments

a. Two Satellite Ranging

Qualcomm plans to phase out Loran-C and replace it with a two-satellite ranging system. This arrangement will provide location accuracy equal to or better than Loran-C and will allow the OmniTRACS terminal to be used in areas of the world where Loran-C coverage is poor or nonexistent. Within the U.S., this will offer the advantage of full 48 state coverage prior to the completion of the Loran Midcontinent Expansion Project and will eliminate Loran-C signal

[13]Speech by Dr. Andrew Viterbi, Qualcomm Inc., at the Phillips Publishing Mobile Satellite Conference, Washington, D.C., 6 November 1989.

interference problems. This feature will be added by modifying some of the NMF and mobile terminal software and leasing a portion of a Ku-band transponder on a nearby satellite. Eliminating the Loran-C receiver will also reduce the cost of the terminal by at least several hundred dollars.

Mobile terminal location will be determined by the network management computer (NMC). To calibrate the system, the NMC will periodically calculate the exact orbital position of each satellite. This is accomplished by using a network of precisely-located benchmark transponders. Once the locations of the satellites are precisely known, mobile terminal range can be accurately computed by measuring the round-trip transit time of signals sent via each satellite to the mobile unit.

A second satellite, located approximately eight degrees from the primary satellite, is used to relay a spread-spectrum signal. This signal uses only a portion of the transponder bandwidth and, to help rapid acquisition, is modulated with the same code sequence as is used on the primary satellite. To obtain the first range measurement, the mobile terminal antenna is quickly shifted from the primary to the secondary satellite. The signal is acquired and a timing measurement is made. The antenna is then swung back to the primary satellite. The primary satellite is then used to obtain a second timing measurement. The timing data are sent to the NMC, where they are combined with a digital terrain map of the Earth to provide a location solution. This is

accomplished in a manner similar to the Geostar 3.0 system described above. Terminal location information will be provided to the dispatcher in the same manner as the Loran-C positions.[14]

b. Other Features

Other optional features include a remote pager to tell when a message has been received by the mobile terminal, automatic trailer identification when picking up or dropping off a load, voice synthesis; interfaces for bar-code readers, trip computers, external control units, and out-of-limit alarms; a panic button, and a solar power option. A rail car terminal has also been developed.[15]

5. System Strengths and Limitations

OmniTRACS was the first available two-way land-mobile satellite communications service. By using previously allotted FSS frequencies, Qualcomm has avoided the spectrum allocation problems experienced by other mobile satellite systems.

Qualcomm's use of existing Ku-band satellites eliminates the financial and technical risk of satellite construction and launch. As a result, far less capital is required to implement an OmniTRACS system. The availability

[14]Interview between Mr. Franklin Antonio, Qualcomm Inc., and the author, November 1989.

[15]Interview between Mr. Bob Carr, Qualcomm Inc., and the author, November 1989.

of multiple Ku-band satellites also eliminates user dependence on one or a few specialized satellites and reduces the risks and impact of satellite malfunction. Since there currently is an excess of Ku-band transponder capacity, Qualcomm may be able to obtain long-term transponder leases at reduced rates.

Uninterrupted transmission of up to 2000 characters enables longer messages to be sent without requiring the operator or equipment to break the character stream up into separate segments. Capacity of the OmniTRACS system is limited by the data throughput rates on the forward and return links. In the event the system approaches saturation, additional Ku-band transponders can be leased and permission requested to expand the system. Heavy rain and snow storms can attenuate Ku-band signals and make reception more difficult. However, the variable rates of data transmission and the reception logic help minimize the impact of this problem. Mobile units used in Hurricane Hugo (Fall 1989) continued to function without interruption.[16]

The OmniTRACS terminal uses widely available commercial Ku-band components. This reduces the cost of the terminal. The OmniTRACS antenna is mechanically and electronically more complicated than an omni-directional antenna, but has proven to be reliable.

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[16]Speech by Dr. Andrew Viterbi, Qualcomm Inc., at the Phillips Publishing Mobile Satellite Conference, Washington, D.C., 6 November 1989.

spectrum. Additionally, a mobile-satellite system which served land and maritime users would require enough bandwidth to provide an adequate capacity for service and to distribute the system's investment cost over a large number of users. Sharing of the assigned AMSS(R) L-band allocations would satisfy both aviation and ground-based users. [Ref. 71:pp. 7-8, 20]

Although the U.S. domestic assignments were changed, they were not consistent with the International Telecommunication Union (ITU) allocations. One of the major issues at the 1987 Mobile WARC was the reallocation of frequencies to the mobile-satellite service. The U.S., Canadian, and Mexican delegates proposed to reallocate the internationally assigned frequencies consistent with the revised U.S. domestic allocation. Preservation of AMSS(R)'s primary status was to be accomplished by using computer equipment to provide automatic priority and preemptive access for all aeronautical communications related to the safety and regularity of flight. [Ref. 74]

The Mobile WARC did not adopt this position. Instead, the exclusive aviation allocation was reduced by four MHz on each link, and these frequencies were set aside for the land-mobile satellite service. As a result, the U.S. and Canada reserved their right to use the bands in the way most appropriate to satisfy their mobile-satellite service

As discussed in Appendix B, when Loran-C receivers are used in the "mid-continent gap," their positioning information will be degraded. This coverage gap will be eliminated by the end of 1990 when the mid-continent expansion project is completed. However, Qualcomm expects to have two satellite ranging operating by the first half of 1990.[17]

E. AMERICAN MOBILE SATELLITE CORPORATION AND TELESAT MOBILE SATELLITE SYSTEM

1. Background

The American Mobile Satellite Corporation (AMSC) and Telesat Mobile (TMI) of Canada will begin jointly operating a North American mobile-satellite system beginning in mid-1993. The system will serve aeronautical, land, and maritime users with a variety of voice and data services.

As discussed in Chapter VI, from an international regulatory standpoint the formulation of a North America mobile-satellite system was controversial. In 1986 the FCC reallocated the domestic Aeronautical Mobile Satellite Service, Route (AMSS(R)) frequency assignments to permit sharing of the band with a Mobile Satellite Service (MSS). This was done because a system dedicated entirely to an aeronautical mobile-satellite system for air traffic control, safety, and regularity of flight would not be economically practicable and would not require the entire allocated L-band

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[17]Interview between Mr. Bob Carr, Qualcomm Inc., and the author, November 1989.

requirements [Ref. 72:p. 3]. Figure 89, located in Chapter VI, illustrates the U.S. frequency allocations.

The FCC awarded a MSS license to the American Mobile Satellite Corporation (AMSC) on 31 May 1989. Consistent with the domestic allocation, a priority Demand Assignment Multiple Access (DAMA) system will be used to recognize levels of message priority to provide AMSS(R) services. Additionally, aviation terminals will have a core capability that meets the minimum standards established by the International Civil Aviation Organization (ICAO) and its special committee on Future Air Navigation Systems (FANS). Teleglobe (Canada) and COMSAT (U.S.) will provide aeronautical services by leasing capacity from TMI and AMSC. A more-detailed discussion of the aeronautical portion of the MSS system is beyond the scope of this thesis.

2. Early Entry System Configuration

TMI and AMSC are developing an early-entry mobile data service which will be available by the Fall of 1990. To provide full coverage of the U.S. and Canada, the Marisat-F1 satellite will be sub-leased from INMARSAT and moved from its Atlantic Ocean position to 106 degrees West Longitude (approximately the same longitude as El Paso and Denver). The early-entry service will function similar to INMARSAT-C, which is described above.

a. User Terminals

Early-entry user terminals will be upwardly compatible so they can be used when the North American MSS becomes operational. This equipment will initially function similar to the INMARSAT-C terminals discussed above. As illustrated in Figures 90 and 91 (located in Chapter VI), the maritime mobile-satellite frequencies are adjacent to the MSS frequencies. To convert from interim to full MSS service, the terminal control software will be changed to use the AMSC and TMI communication protocol and MSS frequencies.

b. Space Segment

The Marisat satellite functions as a "bent pipe" to relay communications traffic. Communication between the terminal and the satellite takes place at the L-band, and the satellite to coast earth-station links are on the C-band. The L-band transponder bandwidth will be divided between AMSC and TMI.

c. Ground Segment

Comsat coast earth-station facilities will be used to provide service to American customers. TMI will utilize teleglobe's earth station facilities. Network operation and packet communications will be similar to INMARSAT-C. [Ref. 96]

3. North American MSS System Configuration

Figure 109 illustrates the general configuration of the AMSC and TMI system. User terminals communicate with the

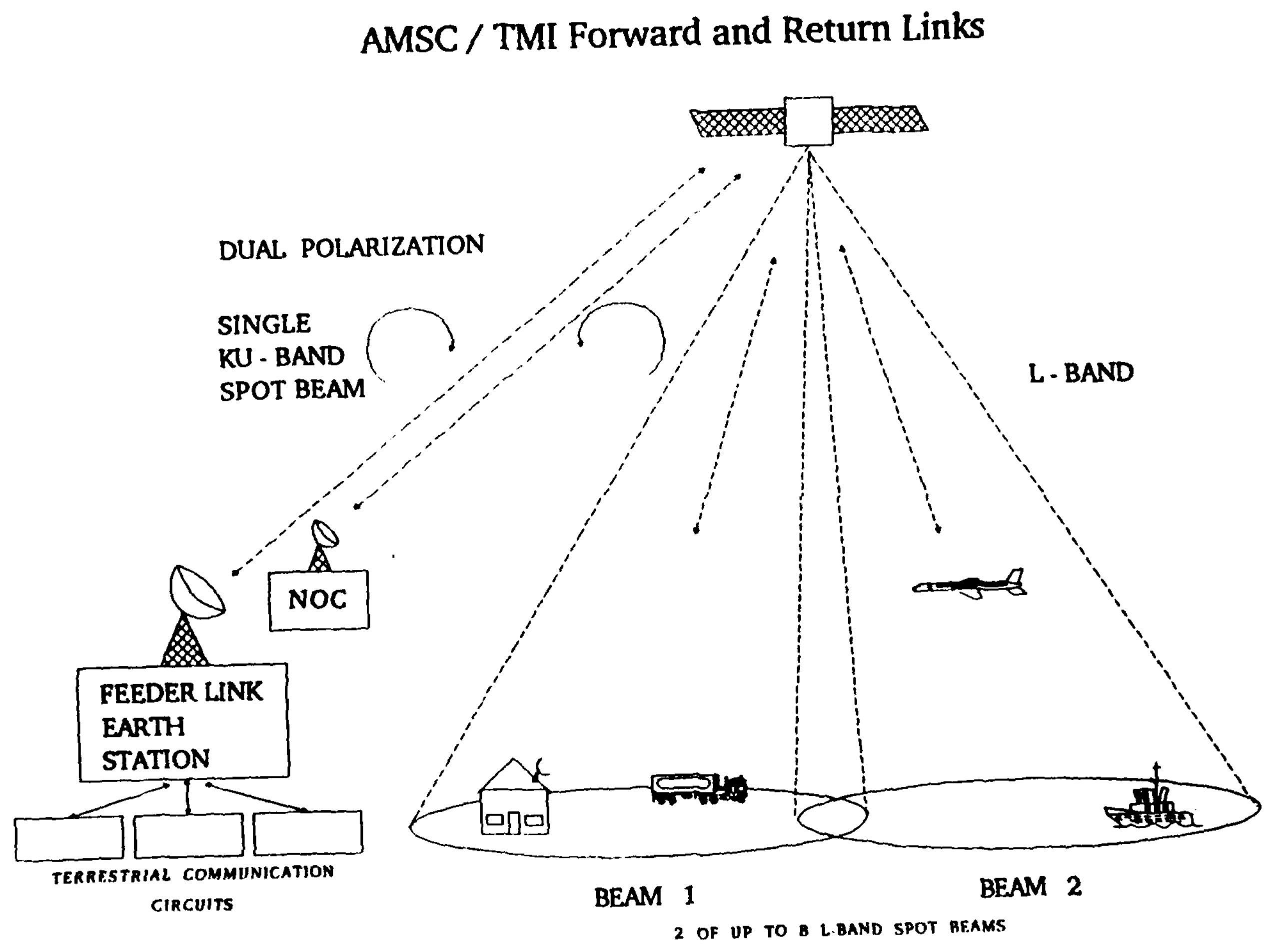

Figure 109. AMSC/TMI Forward and Return Links

satellites via L-band links. Transmissions between the satellites and earth hubs takes place at the Ku-band. The overall operation is governed by the network control center (NCC). Gateway earth stations will interconnect with the public-switched telephone network (PSTN) and data-communication networks. Base earth stations will connect with private communication networks.

a. User Terminals

The diverse requirements for mobile-satellite services will be met by three basic classes of L-band user terminals. Table 26 lists the planned characteristics of each type of terminal.

TABLE 26

L-BAND USER TERMINAL CLASSES

Characteristics	Three Terminal Classes		
Class	Mobile	Mobile	Transportable
Antenna Type	Omnidirectional	Steered	Fixed
Antenna Gain	0-4 dBi	12 dBi	15 dBi
Transmitter Power	10 Watts	2 Watts	1 Watt
Primary Use	Mobile. Light use per terminal.	Mobile. Heavy use per terminal.	Transportable or fixed.
Relative Cost and Complexity	Lowest	Highest	Low

Each type of terminal will be capable of providing voice and/or data communications [Ref. 13:part II, p. 6].

Originally, AMSC and TMI planned to provide both amplitude-compandored single-side band (ACSSB) and digital voice modulation. However, recent advances in low bit rate (4.8 Kb/s) digital voice systems will preclude the use of ACSSB.[18] Terminals can incorporate GPS, Glonass, and Loran-C navigation receivers for position determination. Depending on the available satellite power, terminals will operate in the full duplex mode over approximately 2800 channel pairs. Each channel is spaced in five KHz increments from 1.545 to 1.559 GHz (receive) and 1.646 to 1.6605 GHz (transmit) [Ref. 13:Part II, p. 6]. Figure 110 is a generalized block diagram of a typical user terminal [Ref. 13:Part II, p. 7].

b. Space Segment

AMSC is required to place three satellites into service between July 1993 and July 1994. Telesat Mobile is also planning to launch a MSS satellite by the fourth quarter of 1993. The Canadian and first AMSC satellite will be similar in construction and will be located within a few degrees of each other in orbit. This provides both organizations with a back-up capability in the event one of the satellites fails, and saves each company an estimated $200 million in capital costs [Ref. 97]. The first U.S. satellite will be located at 101 degrees West longitude, the others will be at 62 and 139 degrees West longitude [Ref. 71:p. 19].

[18]Update of modulation format provided by Mr. Keith Fagan, TMI, during a review of the draft thesis.

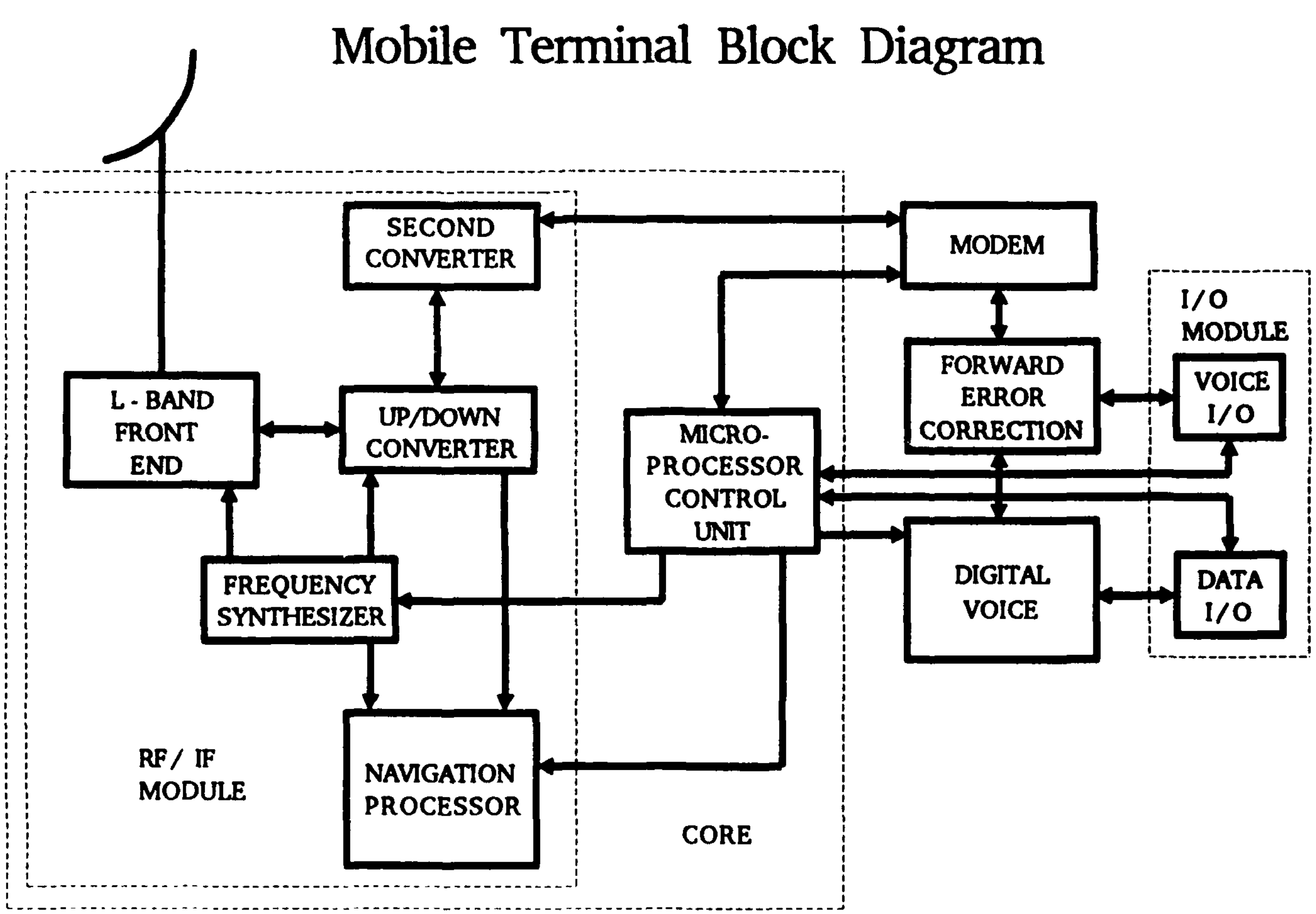

Figure 110. Mobile Terminal Block Diagram

The satellites will operate as a "bent pipe" on the forward and return links. Each satellite will use up to eight L-band spot beams to illuminate the 50 U.S. states, Puerto Rico, the Virgin Islands, Mexico, and Canada. Each beam will be capable of transmitting and receiving over the entire L-band allocation. To prevent interference, adjacent beams will not use the same frequencies, resulting in a frequency reuse factor of 1.5. The L-band beams will be primarily divided into five KHz full duplex channel pairs using a single channel per carrier configuration. This arrangement will provide a capacity of 4200 full-duplex channel pairs per satellite, depending on available downlink power. Frequency sharing between AMSC and TMI will prevent mutual interference. Directional antennas will be used with some terminals. Aside from permitting lower satellite and terminal power requirements, directional terminal antennas will isolate the satellites from each other and permit additional channel reuse. This will increase the total communications capacity of the system.

The L-band beams will be connected directly to the Ku-band feeder links. A single Ku-band spot beam, covering the area described above, will be used for forward and return link communication between the satellite and fixed earth stations. The Ku-band links will occupy 100 MHz in both directions. Dual polarization will be used to provide enough bandwidth to relay up to eight L-band transponder signals plus

the system signalling and control channels. [Ref. 13:Part II, pp. 17-27]

c. Ground Segment

The ground segment is composed of the network control system (NCS) and hubs. The NCS governs the overall operation of the MSS network and controls user access. The NCS contains telemetry, tracking, and control equipment for managing the physical operation of the satellites. The central-packet access controller (CPAC) and priority Demand Assigned Multiple Access (DAMA) processors are housed at the NCS. The CPAC and associated subsystems are responsible for logging mobile terminals into the system, assigning them to packet signalling and data communication circuits, synchronizing their transmission timing, and managing the overall packet communication flow. The CPAC is interconnected with the DAMA processor. The DAMA processor monitors system loading, assigns and retires packet-data channels based on CPAC requirements, and responds to user requests for voice and dedicated data channels [Ref. 14:pp. 131-137]. The DAMA processor recognizes multiple levels of message priority to ensure that safety-related communications can access the network whenever needed [Ref. 13:Part II, pp. 13-15]. As with the U.S. and Canadian satellites, the AMSC NCS and Telesat Mobile NCS are able to provide mutual back-up services.

Feederlink stations will operate at the Ku-band on the forward and return links. As shown in Figure 111,

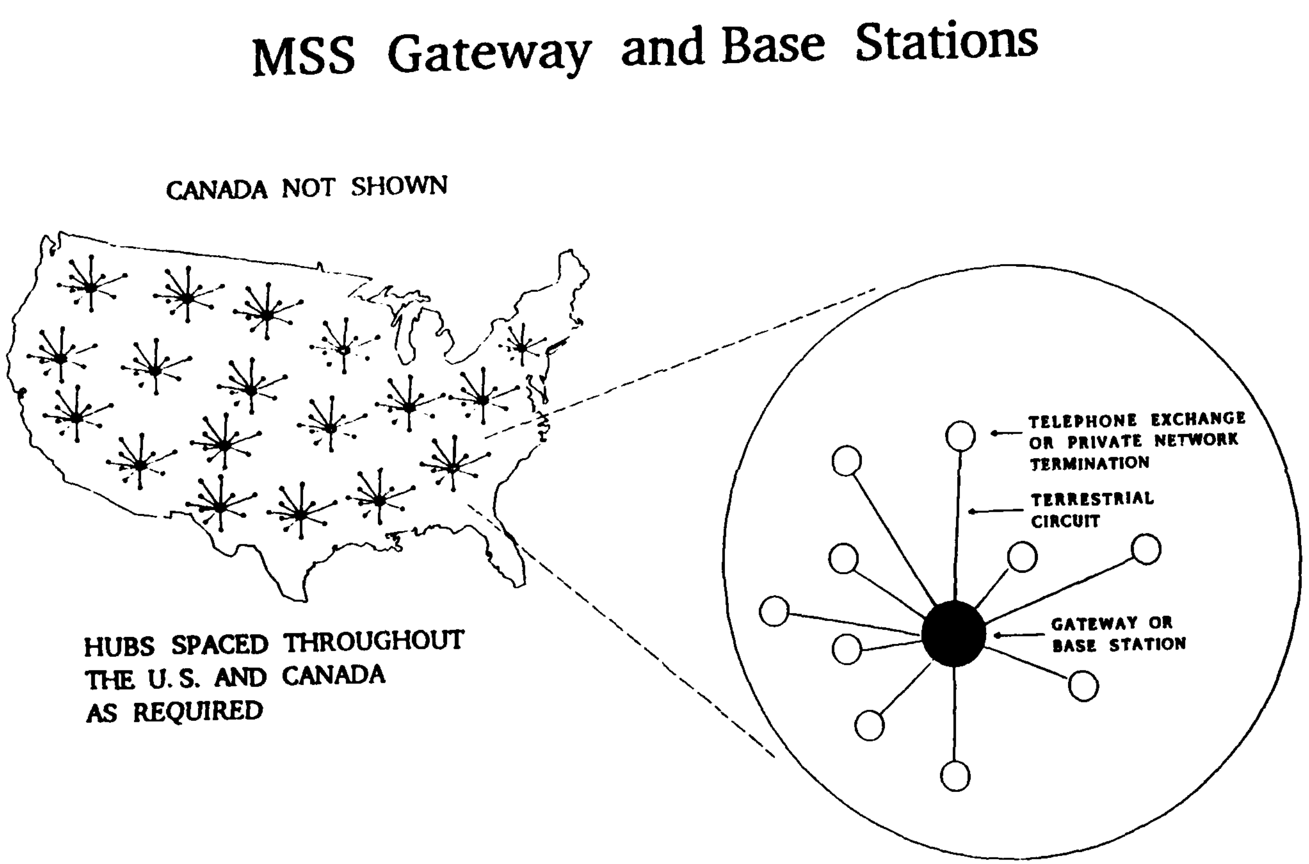

Figure 111. MSS Gateway and Base Stations

feederlinks will be distributed throughout the coverage area to reduce the use of long-distance communications circuits and associated charges.

Feederlinks are divided into two basic classifications. Base stations are used to terminate private network traffic. They are similar to private base stations in the private land mobile radio service and do not interconnect directly with the public telephone and/or data communications systems. Gateway stations will interconnect communications traffic with the public telephone system and/or packet-data networks. Gateways will typically have a capacity of five to 100 or more channels. [Ref. 14:pp. 138-142]

d. Network Architecture

The MSS network architecture is more complex than other single-hub systems because of the number of public and private gateways which will be served. Operation and access to the network is under control of the NCS. The NCS controls and communicates with all terminals and hub stations via time division multiplex (TDM) digital-packet channels. Terminals and hub stations first randomly access the NCS via slotted ALOHA time division multiple access (TDMA) packet-data channels. Once logged onto the system, terminals communicate over assigned TDM channels. Figure 112 illustrates the MSS packet signalling and data communication-network architecture [Ref 14:p. 143].

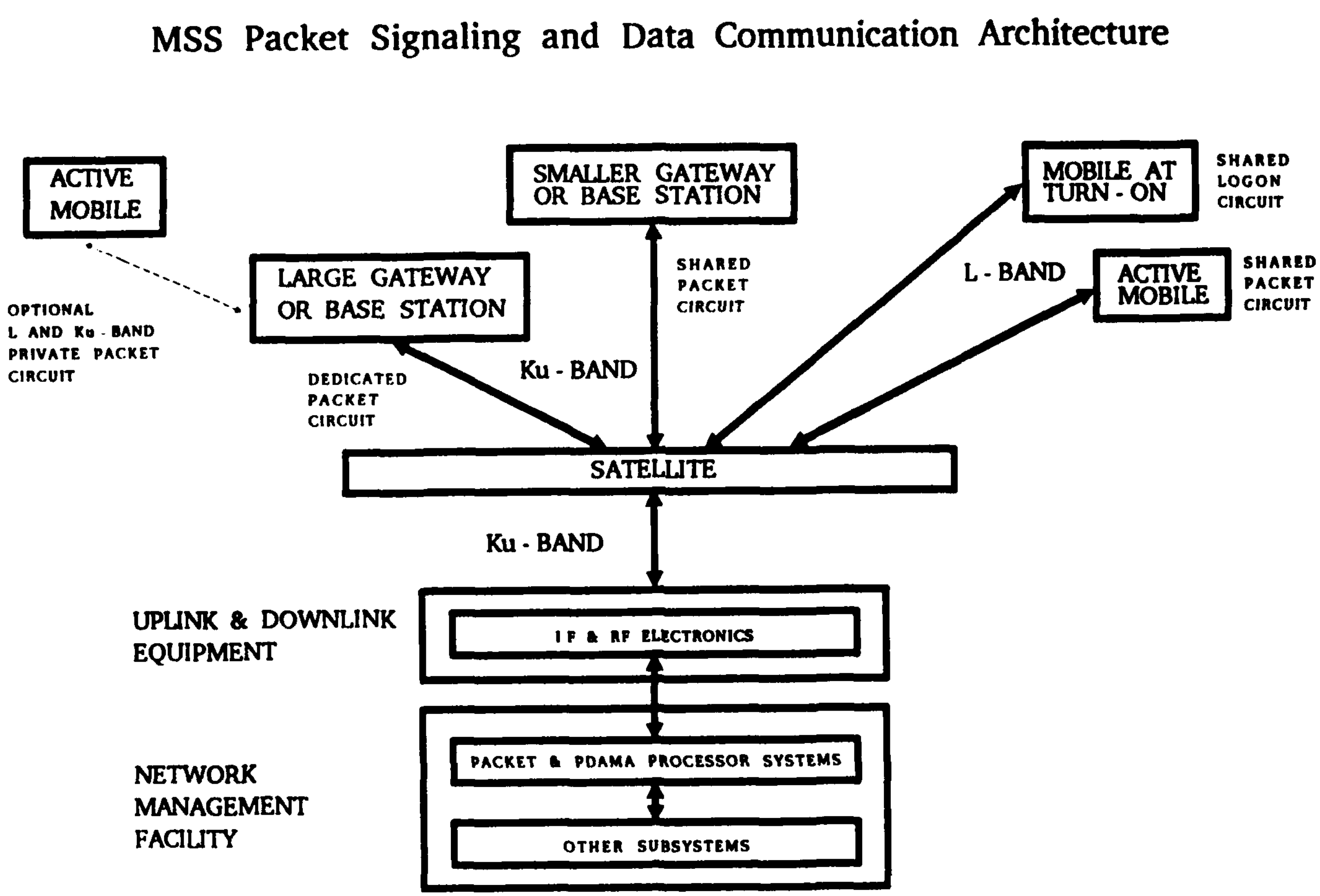

Figure 112. MSS Packet Signalling and Data Communication Architecture

4. System Operation

a. User Logon and Logoff

The NCS continuously uplinks a minimum of one outbound logon channel per spot beam. Each outbound logon channel continually repeats information about additional temporary logon channels along with the NCS's responses to terminal logon requests. When a terminal is first turned on, it searches through the programmed frequency assignments until it locates an outbound logon signal of sufficient strength. The terminal then transmits a logon request message on the associated TDMA inbound channel. An approximation of the signal transit time delay is used to provide coarse TDMA slot synchronization. This increases the amount of inbound traffic which can be handled on the logon channel. If the terminal's logon request is not acknowledged because of a collision with another terminal's message, then each terminal will automatically retransmit after a random interval. When the logon message successfully reaches the NCS, the receiving equipment measures the received time error relative to the slot timing. The NCS responds to the terminal with a transmit delay correction and assigns a different packet circuit to be used by the terminal. The terminal adjusts its transmit delay time accordingly and tunes to the assigned packet circuit. If the terminal is moving, the slant range to the satellite and transmit time delay will gradually change. To compensate, mobile terminals will occasionally repeat the logon procedure

to update the slot timing delay. Figure 113 illustrates the logon procedure [Ref. 14:pp. 144-146].

The NCS can command a mobile terminal to shut down if the terminal makes uncontrolled or illegal transmissions. When a terminal leaves the system, a power-down signal is sent via the packet-data channel to the NCS. The NCS transmits an acknowledgement, and the terminal shuts down.

b. Packet Switched Data

When a packet-data terminal logs onto the system, the NCS CPAC will assign it to a packet circuit based on the location of the spot beam and the terminal's requested or assigned earth hub. Data packets will be 256 bits long and transmitted at 2.4 kbps using forward-error correction. The types of packet data calls are listed in Table 27.

TABLE 27

TYPES OF PACKET DATA CALLS

* Mobile-to-base--very short message
* Mobile-to-base--one-way
* Mobile-to-base--two-way
* Base-to-mobile--receive only (no receipt acknowledgement)
* Base-to-mobile--one-way
* Base-to-mobile--data collection request
* Base-to-mobile--two-way
* Base-to-mobile--broadcast (no receipt acknowledgement)
* Base-to-base

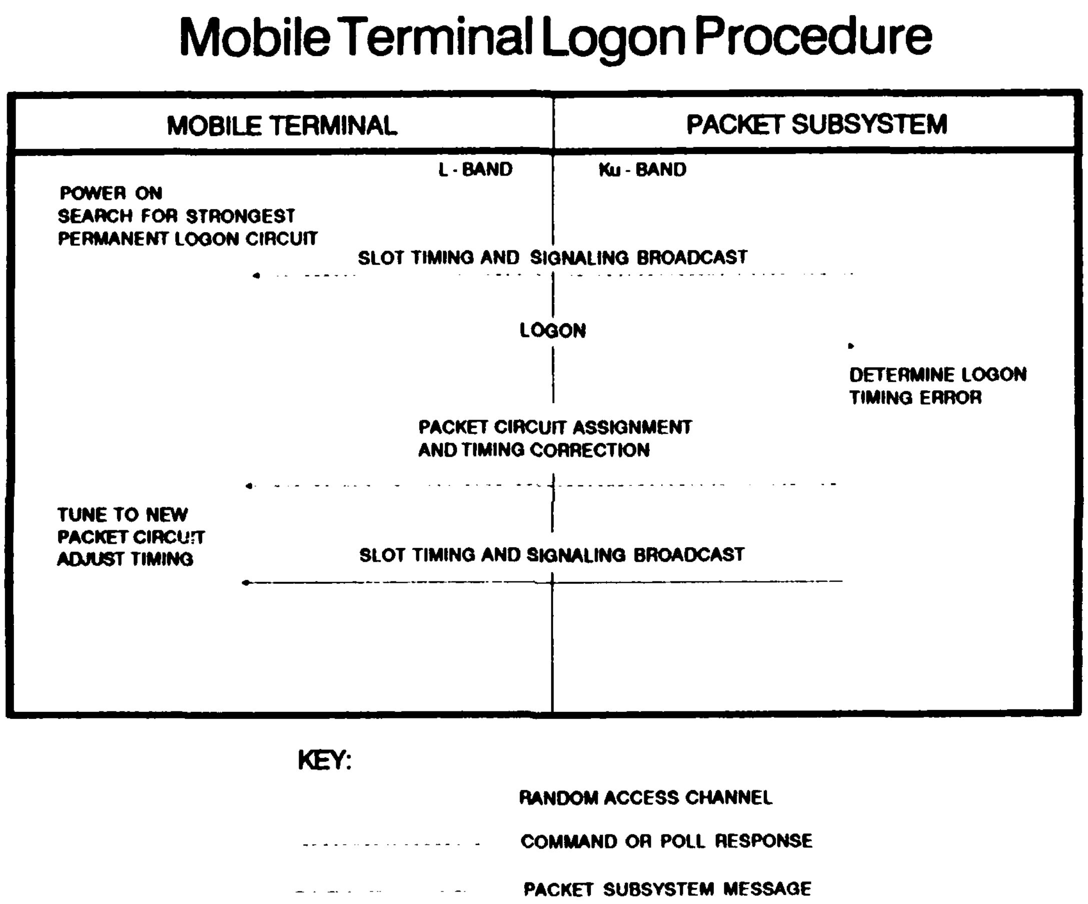

Figure 113. Mobile Terminal Logon Procedure

Mobile-to-base packet communications are illustrated in Figures 114 and 115, and are representative of the logic used for all types of packet-data calls listed above. The very short message mode allows abbreviated packet data messages to be efficiently sent. To transmit a message, the user enters a brief code or the terminal converts a canned message into a short character string. The send button is pressed and the terminal transmits the message along with the terminal and destination address directly into a slotted ALOHA packet circuit. The terminal will automatically retransmit after a certain period if no acknowledgement is received.

For longer one-way mobile-to-base communications, the user keys in the message and presses the send button. The terminal calculates how many packets will be required, and sends a short message to the NCS requesting a transmit time and space allocation. The NCS replies, and the terminal transmits in accordance with its instructions. The correct receipt of each packet is acknowledged by the CPAC, and incorrectly received packets are retransmitted. After all packets are correctly received, they are routed by the CPAC over Ku-band links to the appropriate hub. The destination's acknowledgement is forwarded via the CPAC back to the terminal. [Ref. 14:pp. 146-151]

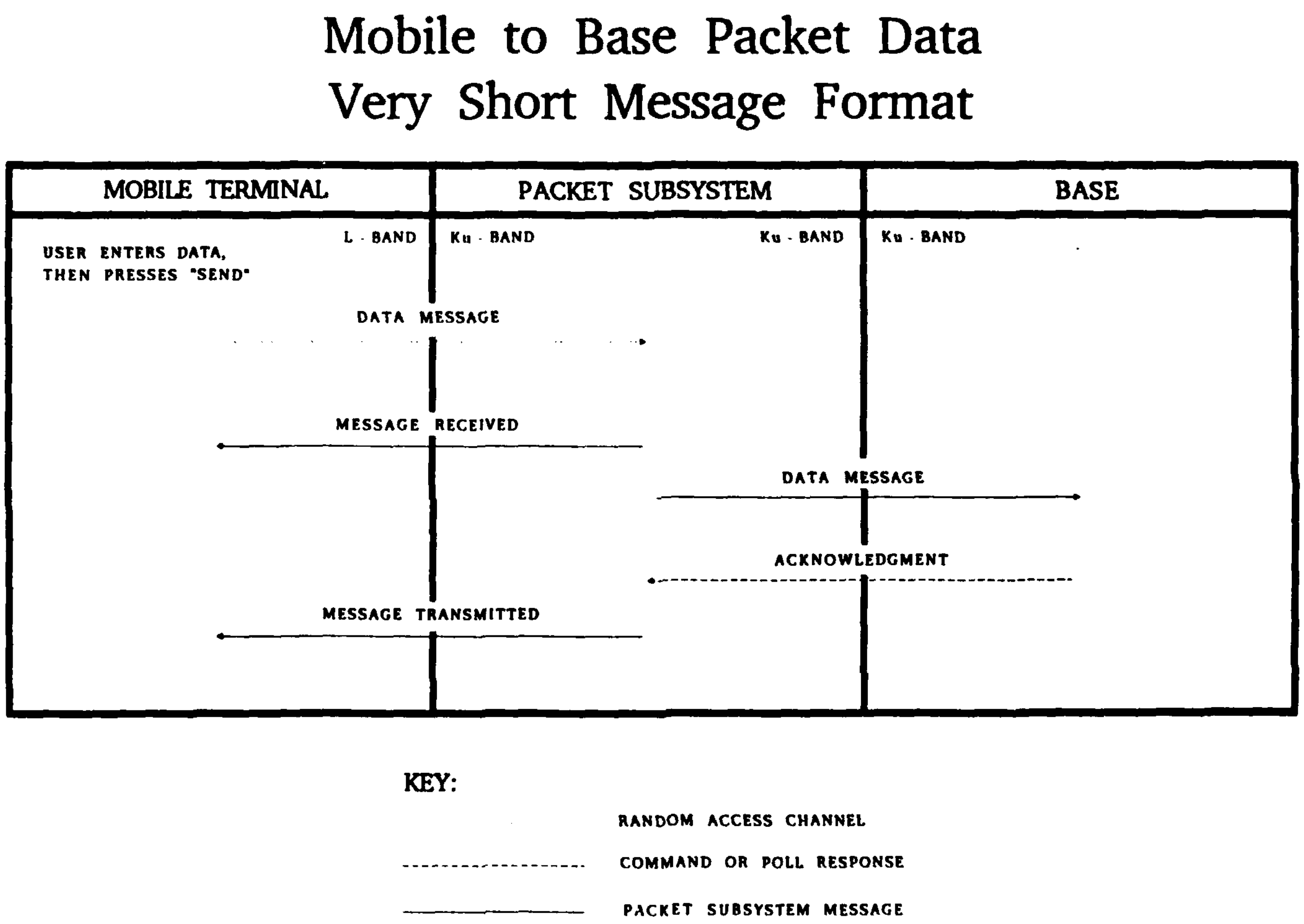

Figure 114. Mobile to Base Packet Data Very Short Message Format

One Way Mobile to Base Packet Data

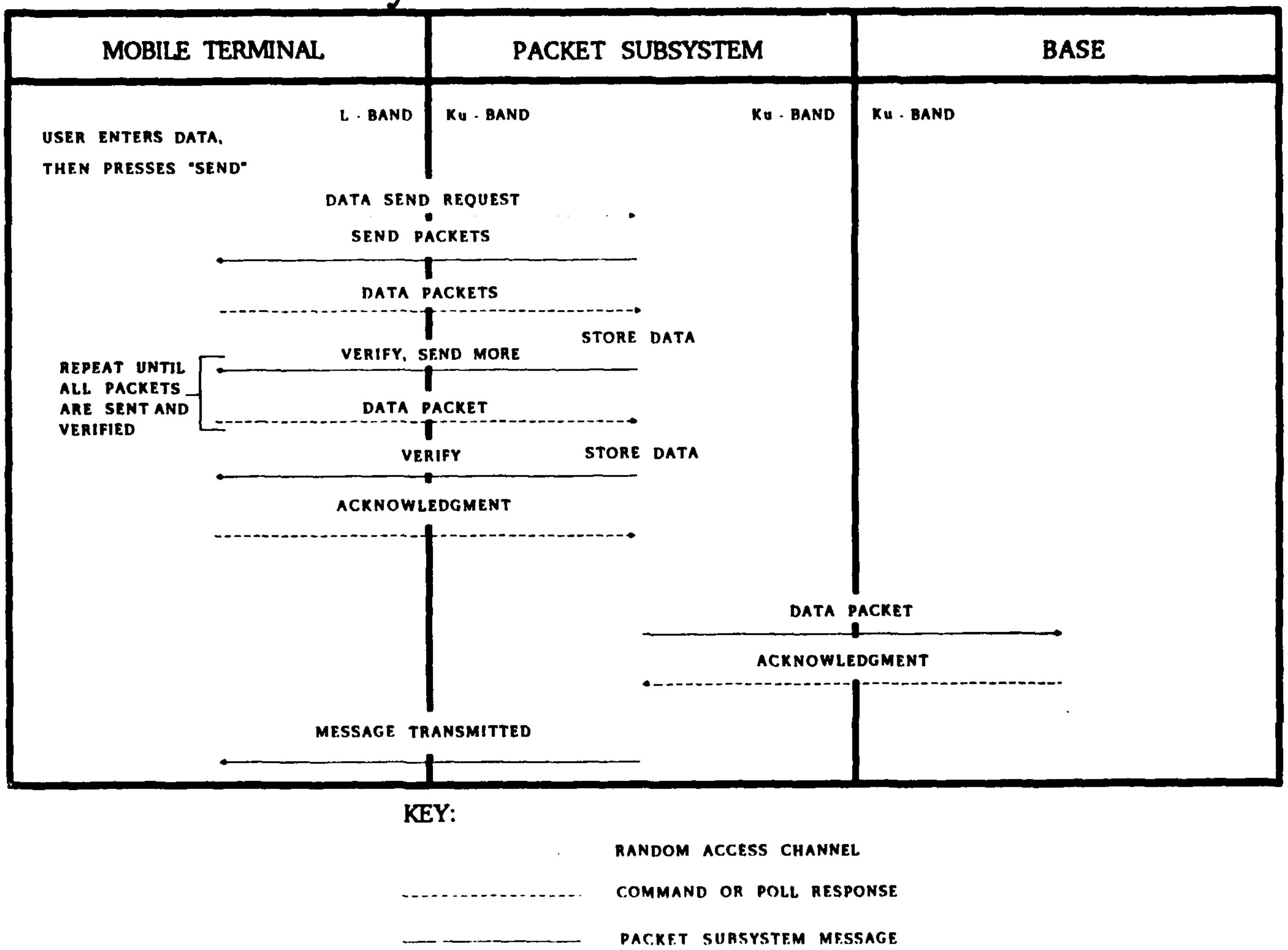

Figure 115. One-Way Mobile to Base Packet Data

c. Demand Assigned Multiple Access (DAMA) Voice and Data Communication

The function of the DAMA processors is to provide the maximum utilization of the available spectrum. This is accomplished by assigning voice and data channels based on user requests and preemptive priority sequence. To permit the most efficient use of the limited number of channels, the circuits are not assigned until the called party actually answers. This provides a significant increase in the number of channels available at any given time.

The types of DAMA voice and data communications are listed in Table 28.

TABLE 28

DAMA VOICE AND DATA COMMUNICATIONS

* Mobile-to-gateway
* Gateway-to-mobile
* Mobile-to-base
* Base-to-mobile
* Base-to-mobile (broadcast)
* Mobile-to-mobile (via a double hop through the satellite)

Note: The above references to "mobile" also apply to transportable terminal service.

Table 29 lists the proposed grades of voice services.

TABLE 29

GRADES OF VOICE SERVICES [Ref. 13:Part II, p. 28]

Type	Data Rate (Kbps)
Emergency (Digital)	2.4
Digital, Communications Quality	4.8
Digital, Toll Quality	16.0
(Bandwidth will occupy four channels)	

The description of mobile-to-gateway service is representative of how the NCS equipment functions. The setup of a voice or dedicated data circuit is illustrated in Figure 116. Before the call, the terminal is in an idle state and is monitoring its assigned packet-signalling circuit. When the user makes a call, the phone number is keyed in and the send button is pressed. The terminal sends a request message containing the destination phone number and terminal identification over the packet channel to the NCS. If the data collides with another user who transmitted at the same time, no acknowledgement will be received and the terminal will retransmit after a random interval.

The called number is used to identify the appropriate gateway or hub station to the NCS. The NCS selects and acquires control of a gateway modem by sending the appropriate commands and the called number over a packet circuit. The gateway or hub acknowledges the command over a return packet channel, and places a telephone call to the

Call Setup
Mobile to Gateway (Voice)

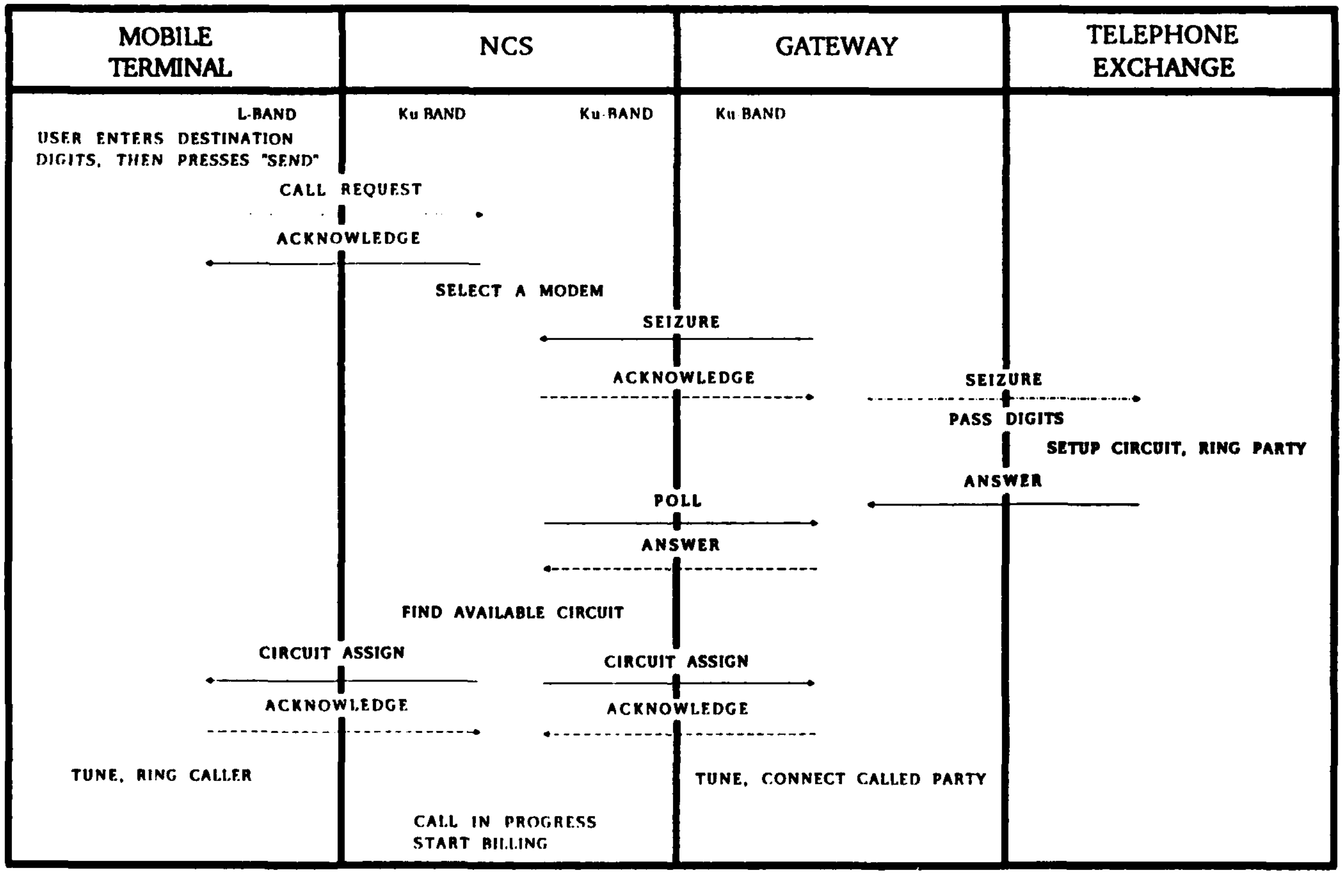

Figure 116. Call Setup Mobile to Gateway (Voice)

requested number or over the designated private circuit. When the party answers, the gateway sends another packet message to the NCS indicating the connection has been made. The DAMA processor then selects an available circuit, assigns it to both parties over packet links, and the call takes place. It is estimated that the typical delay before communication can occur will be about one second after the called party answers.

When the mobile user ends the call, the terminal sends a hang-up message to the NCS. The NCS acknowledges the message and sends a hang-up message to the hub station. When the hub user hangs up first, the NCS will send a disconnect message to the mobile terminal. In either case, when the disconnect is acknowledged the circuit is immediately released back to the available pool. [Ref. 14:pp. 152-156]

d. Additional Services

AMSC and TMI plan to broadcast radio navigation integrity messages (GPS, Glonass, Loran-C, etc.) to warn users of any planned outages or system problems. GPS and Glonass differential corrections, obtained from a network of receivers spaced throughout the coverage area, can be broadcast to enable users to refine the accuracy of their calculated position. National Institute of Standards and Technology time signals can also be broadcast to provide users with high precision time measurements.

5. System Issues

Unlike other North American mobile-satellite systems, the AMSC and TMI system is capable of providing both voice and data services. The ability to use voice in areas which cannot be economically served by terrestrial radio systems frees mobile users from the requirement to use a satellite data terminal and keyboard. Aside from the obvious convenience of being able to simply talk, this will benefit users in those situations where a data terminal would be difficult to use, such as when the information to be conveyed is of a non-routine nature and the use of a keyboard would be too time consuming. An example is in the area of emergency communications, where voice conversations are the most rapid and flexible means of conveying information. Voice may also be appropriate as a back-up in systems which primarily use data for communications. The use of transportable or inexpensive fixed terminals will enable users in remote locations to be provided with telephone services that, for economic or physical reasons, would not otherwise be provided. Dedicated channels also allow proprietary data formats or encrypted data to be conveyed in real-time through modems. This capability is not available with other mobile-satellite systems. However, voice and dedicated data communication circuits will be more costly than packet-data services because of the inability to simultaneously share a frequency with other users and the greater power and bandwidth requirements for some

types of voice services. AMSC's rate structure will take this into account [Ref. 13:Part 1, p. 26].

The ability of TMI and AMSC to use the same communications protocols and identical ground, space, and terminal equipment provides economies of scale that would not be possible with separate MSS systems. Multiple terminal suppliers will compete with each other based on price and features. Likewise, numerous earth gateway stations will compete for a share of the communication traffic. When combined, these factors will help reduce costs to both service providers and service users.

F. GEOSTAR MESSAGING CORPORATION DIGITAL LAND MOBILE SATELLITE SERVICE

1. Background

In June 1988, Geostar Messaging Corporation (GMC), a wholly-owned subsidiary of Geostar Corporation, petitioned the FCC to establish a Digital Land Mobile Satellite Service (DLMSS) [Ref. 58]. As a basis for its petition, GMC cited the very large potential market for digital communication services. GMC stated that this market exceeds AMSC's capacity because MSS is optimized for voice services. GMC also stated that RDSS is not structured to support digital messages of a substantial length. GMC's proposed DLMSS was specifically designed to provide low bit-rate (up to 4800 bits per second) data transmissions of any length to mobile users [Ref. 58:p. 12]. Although the MSS and RDSS systems do offer overlapping

services, GMC stated that its proposed DLMSS system will fill a well-defined market niche. Market overlaps in the three systems would sharpen competition and multiply product and service options to the public [Ref. 58:p. 3]. GMC claimed that its system was ideally suited for packet or circuit-switched data communications, facsimile, digital paging and dispatch, and digital voice [Ref. 58:pp. 12-14].

To implement DLMSS, GMC requested that the Commission domestically allocate, on a co-primary basis, the entire L-band spectrum which was made available to land mobile-satellite services at the 1987 Mobile WARC. [Ref. 58:p. 15] These allocations are detailed in Chapter VI. Additionally, GMC requested the FCC authorize "bi-directional" operations for DLMSS. This spectrum-reuse arrangement would permit the sharing of almost the entire L-band allocation with INMARSAT by interchanging the DLMSS uplink and downlink frequencies. DLMSS terminals would transmit on INMARSAT downlink frequencies, and receive on INMARSAT's uplink frequency. Mutual interference in the costal areas would be controlled by judicious frequency assignment and other techniques [Ref. 58:pp. 24-25].

As discussed in Chapter VI, the FCC found GMC's reverse band proposal to be infeasible because of the potential for severe mobile-to-mobile interference. [Ref. 57:p. 4]

2. System Costs and User Charges

Based on GMC's 1988 proposal, costs to orbit an interim service "add-on" DLMSS satellite package were estimated at $79 million. Construction was planned to start in 1988, with launch by the end of 1990. The proposed ultimate configuration of two advanced DLMSS satellites would cost $276 million for construction, launch, and insurance. Construction of these satellites was planned to commence in 1989 and 1990, respectively. Total costs of the DLMSS proposal were estimated to be $355 million [Ref. 58:App. K]. Portable terminals are estimated to be initially retailed for under $3000, with the price dropping to $1200 in three years. Future versions of the terminals are expected to cost between $300 and $500 [Ref. 58:p. 12].

Proposed user charges were $2.00 per minute at 4800 bits per second (bps), $0.50 per minute at 1200 bps, and $0.25 per minute at 600 bps [Ref. 58:p. 11]. Based on the DLMSS system beginning operation in 1990, 465,000 organizational customers were expected to generate revenues of $558 million by 1997 [Ref. 58:p. D-16]. Personal users were expected to raise the total to around $1.1 billion, with a net income of $490 million [Ref. 58:App. K].

3. System Configuration

The proposed DLMSS satellites are distinguished from other mobile satellite "bent-pipe" systems by incorporating a complete on-board message routing processor and subscriber

database. The satellite directly performs the customer verification and routing functions which are accomplished on the ground by INMARSAT and AMSC/TMI equipment. This allows single hop mobile-to-mobile communications within the L-band. Mobile-to-base communications would also take place entirely at the L-band. Ka-band links (20/30 GHz) would be used to control the satellite, monitor and govern the communications system, and act as feeder links only for store and forward services [Ref. 58:App. A., pp. 2-9].

a. Interim "Add-on" Service

The interim add-on package was to be integrated with a host spacecraft assigned to an orbital location between 85-120 degrees West Longitude. The satellite would use two spot beams to cover the continental U.S. Normal or bi-directional operation could be used. [Ref. 58:Tab 19]

b. Dedicated DLMSS Spacecraft

Two dedicated satellites, located at 115 and 110 degrees West longitude, would use eight spot beams to provide coverage of the continental U.S., Alaska, and Hawaii. [Ref. 58:Tabs 17-18]

3. System Operation

The system signaling and call setup logic was designed to function similar to the INMARSAT and AMSC/TMI system. However, equipment aboard the satellite performs the actual circuit assignment and switching function. [Ref 58:App. G]

4. System Issues

The use of onboard switching equipment would reduce the amount of spectrum required for satellite feeder links. This is because control and switching signals do not have to be relayed between NMF and the satellite. This also reduces system response time to call set-up and take-down requests. The proposal to use bi-directional operation between 1.530 GHz to 1.544 GHz and 1.6265 GHz to 1.6455 GHz would have required extensive coordination of frequencies with INMARSAT. Consideration of the international policy issues would also have been required.

G. ORBITAL COMMUNICATIONS CORPORATION PROPOSAL FOR A LOW-ORBIT MOBILE SATELLITE SYSTEM

1. Background

On 28 February 1990, Orbital Communications Corporation (ORBCOMM) submitted a proposal to the FCC to establish a mobile data service using low-earth orbit (LEO) satellites, and requested authority to begin construction of its proposed system [Refs. 77, 78].

ORBCOMM is a wholly-owned subsidiary of Orbital Sciences Corporation (OSC). OSC was formed in 1982 to develop and operate space transportation systems and engage in other space-related businesses. OSC has developed the Transfer Orbit Stage (TOS) orbit transport vehicle and the Pegasus Air-Launched Space Booster which has been successfully tested and is now in production. OSC's Space Data Division is a

developer and manufacturer of suborbital rockets, launch facilities, space payloads, and associated electronics and data systems. [Ref. 78:pp. ii-iii]

ORBCOMM proposes to use digital-packet switching technology and confine the system to non-voice, low speed, alphanumeric transmissions. A total of 878 KHz of spectrum is requested to support between ten and 20 million U.S. subscribers, of which over 85% are expected to fall into the emergency services category. Mobile terminal location will be determined by doppler shift. GPS time signals, accurate to one microsecond (one-millionth of a second) will also be provided free of charge to any user [Ref. 77:p. 22]. The key to ORBCOMM's market optimism is the ability to use simple whip antennas and existing VHF and UHF components to achieve retail terminal prices ranging from $50 to $400 [Ref. 78:p. 99]. ORBCOMM plans to construct a complete U.S. system for an estimated $320 million, with the space segment accounting for $172 million of this cost [Ref. 78:p. 116]. Since the entire earth will be covered by the satellite constellation, world-wide coverage could be provided by expanding the number of ground stations and networks. This would allow other nations (including underdeveloped or less-densely populated countries) to obtain these communications services with only a small investment in earth-station gateways [Ref. 77:p. 16].

2. Service Description

ORBCOMM plans to offer four types of services to meet subscriber needs. The differences between service offerings will primarily hinge on terminal equipment and system operation.

a. SecureNet Emergency Service

This service will be tailored to meet the needs for low-cost, ubiquitous emergency services. This configuration will provide real-time, two-way priority communications analogous to "911" telephone services. Only short-coded messages and terminal location will be transmitted, and the sender will be notified that the message was received. The unit can be hand-carried or incorporated into motor vehicles and equipped with an impact sensor to trigger a distress message in the event of an accident. The terminal could also be used to report vehicle theft. Power would be supplied by the vehicle's battery, and the antenna shared with the vehicle radio. The unit could be upgraded with a keyboard for enhanced two-way messaging. [Ref. 78:pp. 36-39]

A basic portable terminal with emergency signalling capability only is planned to retail for around $50 when produced in large quantities. Adding doppler positioning circuitry would raise the price to around $150. Annual subscriber fees will range from $30 to $50, depending on the type of service, plus a fee for each use. [Ref. 78:p. 46]

b. DataNet Data Acquisition Services

This service will be oriented toward business, industrial, and environmental applications where data need to be collected from multiple remote points and transmitted back to a central processing center. Subscribers to this category of service would be interested primarily in a one-way, inbound flow of data on a regular or out-of-tolerance condition. However, the service will provide an outbound link to poll the remote terminals for requested data broadcast, for remote system checks, and message receipt confirmation. The terminals are expected to be used in fixed locations and will not incorporate the location calculating circuitry. This will lower the terminal cost. [Ref. 78:pp. 39-40]

c. MapNet Tracking Services

MapNet is designed for applications where the basic requirement is to know where property, vehicles, or persons are located. Position reports can be obtained either by polling the terminal or upon the expiration of a pre-set terminal timer. Expected uses are transportation vehicle and shipping container monitoring, anti-theft, and animal tracking. [Ref. 78:pp. 40-41]

d. VitalNet Message Services

This service is designed to meet the needs of those who require two-way communications and position reporting from any location. The terminals will be designed to accommodate messages of up to 150 characters in length, and

it will be possible to connect the equipment to printers or transfer information to computers.

It is envisioned that these terminals would have a suggested retail price of $250 to $300, and that monthly subscription charges will be around $35 plus a flat charge for each message. [Ref. 78:p. 50]

e. Standard Time and Frequency Broadcasts

ORBCOMM also proposes to provide any user, free of charge, a stable 400 MHz frequency source and time signals accurate to one microsecond. Time signals will be obtained from GPS satellites. [Ref. 78:p. 20]

3. System Configuration

The proposed system uses 20 small satellites in circular orbits 970 km (600 statute miles) above the Earth. Two of the satellites will be in polar orbits, and 18 of the satellites will be placed in orbits inclined to the equator by 40 degrees. The low-altitude orbits will reduce the power required for communications by a factor of up to 1000 (30 dB) when compared to geostationary satellites. VHF and UHF frequencies will be used for mobile communications. [Ref. 78:pp. 3-4]

a. Proposed Frequency Plan

Table 30 illustrates the proposed frequency plan [Ref. 78:p. 18].

TABLE 30

PROPOSED FREQUENCY PLAN

Downlink	Frequency (MHz)	Channels	Required Bandwidth KHz per Channel	Total KHz*
User Terminals	137.000-137.270	8	27	270
Regional Gateway	137.300-137.400	1	90	100
Time/Frequency	400.075-400.125	1	40	50
Uplink				
User Terminals	148.000-148.378	20	15	378
Regional Gateway	148.700-148.800	1	90	100
			TOTAL	899

* Includes guard bands

The 137-138 MHz band is shared between government and non-government users. ORBCOMM's proposed frequency plan avoids the frequencies used by band occupants. The 148-149.9 MHz band is also shared between government and non-government users, with the latter being comprised of experimental licenses. The principal users of the band are the military services. Transmissions are generally between mobile units and confined to military installations. ORBCOMM does not consider mutual interference to be much of a problem due to the geographical dispersion of military bases, the line of sight propagation of VHF transmissions, and the burst transmission mode used by the terminals. However, the uplink channelization plan was being restructured at the time this thesis was being written to provide additional interference protection. The distribution of uplink channels throughout

the 149-149.9 MHz band will be changed, and mobile terminal frequencies will be spaced between the 25 KHz-wide FM military channels. This will help minimize the uplink interference from terrestrial radios because only the loudest voice modulation peaks will cause the FM carrier to travel to the edges of the channel.[19] Additionally, a satellite-subsystem spectrum analyzer will scan the uplink bandwidth and sense the level of government FM transmissions. When the aggregate signal levels are high enough to cause potential interference in the satellite receiver, commands will be issued via the downlink to exclude certain uplink frequencies. The mobile terminal frequency synthesizer will then lock out these channels until further notified. Single-channel units will use frequencies where potential interference is minimal or non-existent.[20] Regional gateways are planned to be located and shielded to preclude any interference from military users. The 400.1 MHz band is unoccupied [Ref. 78:App A, pp. 3-[illegible]. Use of satellites on all three frequencies is consistent with international allocations [Ref. 78:App. A, Table 1].

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[19]As discussed in Appendix B, with FM modulation, the magnitude of the carrier shift is driven by the volume or "loudness" of the information to be communicated, while the carrier frequency is shifted proportionally to the information to be communicated.

[20]Telephone conversation between Mr. Alan Parker, President of Orbital Communications Corp., and the author, 1 June 1990.

b. User Terminals

Subscriber terminals will be manufactured and marketed by the consumer electronics industry, and will fall into three categories: basic portable terminals, enhanced-performance portable terminals, and mobile terminals. Portable terminals will transmit with a power of two watts, and mobile terminals will use five watts. Transmissions will take place at 1200 bps and be frequency shift-key (FSK) modulated. Reception of satellite phase shift-key (PSK) modulated signals will be at 4800 bps. Antennas will vary depending on the application. Portable units will have simple flexible or retractable antennas between 23 cm and 46 cm (nine inches and 18 inches) in length. Automotive applications will be able to share the use of the antenna with AM/FM radio functions.

The basic transceiver will have a single transmit channel which is randomly assigned during the manufacturing process. Enhanced terminals will have three or more transmit channels for faster satellite access. The transmit and receive subsection will be built from existing high production volume components. The digital processor circuitry will reside on a single custom-integrated circuit. Power for portable units will be provided by batteries. [Ref. 78:pp. 99-102]

The circuitry required for doppler position fixes will supplement the communications electronics. There will be

two types of navigation terminals: single-channel receiver units operating at 137 MHz, and a dual receiver unit operating at 137 MHz and 400 MHz. In both cases, the 137 MHz receiver will serve communications and position determination functions. The 400 MHz time signal helps to improve the position solution. Doppler position fixes will take about seven minutes. The terminals can be linked to a Loran-C or GPS navigation receiver if more frequent and immediate position reports are required [Ref. 78:pp. 110-112].

c. Space Segment

The ORBCOMM space segment is covered in greater detail because of the types of orbits and launch vehicle used.

(1) Orbit Selection and Ground Coverage.

Orbital parameters such as altitude and inclination are driven primarily by the degree and the type of ground coverage required by the system. In addition, considerations such as orbital life also have a significant impact on their choice. With low-earth orbit satellites, orbital altitudes below 800-900 km begin to suffer from the effects of air drag resulting in costly propulsion systems to maintain precise orbit position and shortened life. Above this altitude, the effects of drag are minimized, although the solar radiation pressure becomes more significant. To achieve an optimum balance between the two forces, and to obtain the maximum operating life, the 20 satellite ORBCOMM system will be placed in a circular 970 km (600 statute mile) orbits. [Ref. 78:p. 60]

To obtain the optimum tradeoff between single coverage and the minimum launch/replacement costs, the primary ORBCOMM constellation will be comprised of three planes with six satellites in each plane. The planes will be separated by 120 degrees and the satellites within a plane by 60 degrees. Polar coverage is achieved with the two polar orbiting satellites. These planes will be orthogonal (intersecting at right angles) with the satellites 180 degrees out of plane. [Ref. 78:p. 61]

> ORBCOMM's satellite system will provide near-continuous high quality coverage to essentially all of the area of the globe bounded by the 70 degree latitude grids. Polar area coverage will be provided every one-half hour for 14 minutes ...satellite footprints provide the coverage outlined in the following table [Ref. 78:p. 76]:
>
> | Elevation Angle | Coverage Area | Coverage Time |
> |---|---|---|
> | 5 degrees | 5566 km | 14 minutes |
> | 10 degrees | 4675 km | 12 minutes |
> | 15 degrees | 3785 km | 10 minutes |

Figure 117 illustrates the ground track for one satellite plane at one point in time. Figure 118 depicts the coverage area obtained by the constellation of 20 satellites at any one point in time. Near-continuous coverage will be provided 95% of the time within the boundaries of plus-and-minus 70 degrees latitude. [Ref. 78:p. 76]

(2) Launch Vehicle and Orbital Stationing. ORBCOMM plans to use the Pegasus Air-Launched Space Booster to place the 20 satellites in orbit. This new type of launch vehicle will be used to orbit the experimental DataSat satellite in late 1990, and is described below:

> OSC has developed the Pegasus Air-Launched Space Booster specifically for the purpose of quickly and efficiently placing small satellites into low-earth orbit. Pegasus payloads are integrated into the vehicle at ground level, and the vehicle is carried by an aircraft to an altitude of approximately 43,000 feet before it is released and the rocket engine is ignited. The Pegasus is designed to achieve more efficient performance than a comparable ground-launched rocket due to several factors: the energy imparted by the velocity and altitude of the carrier aircraft, reduced drag at launch altitudes, better propulsion efficiency at high ignition altitudes, and reduced gravity losses attributed to the Pegasus wing. Other factors that contribute to the greater efficiency of the Pegasus include flexibility in selection of launch point, the availability

Satellite Coverage for Single Plane[1]

[1] Zero and Five Degree Elevation Angles

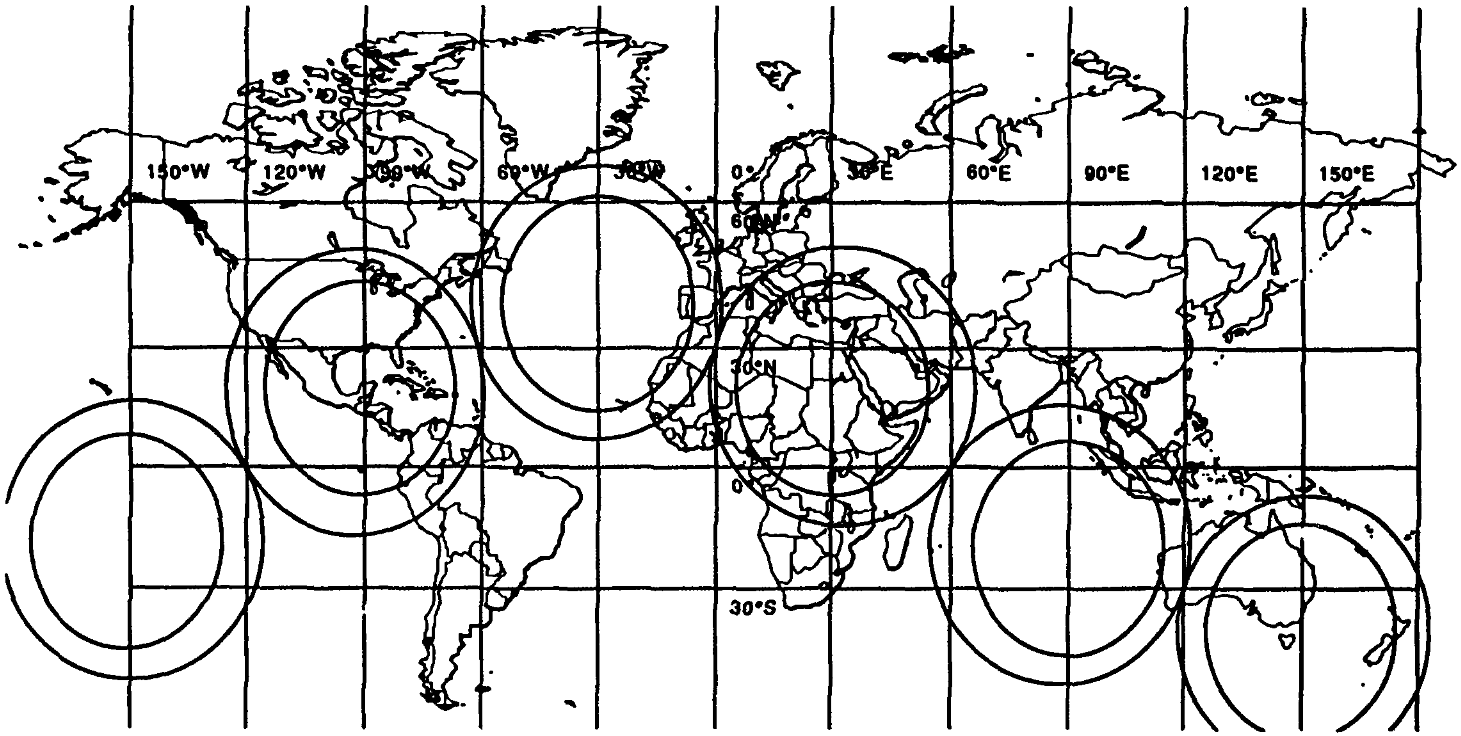

Figure 117. Satellite Coverage for Single Plane

Twenty Satellite System Coverage

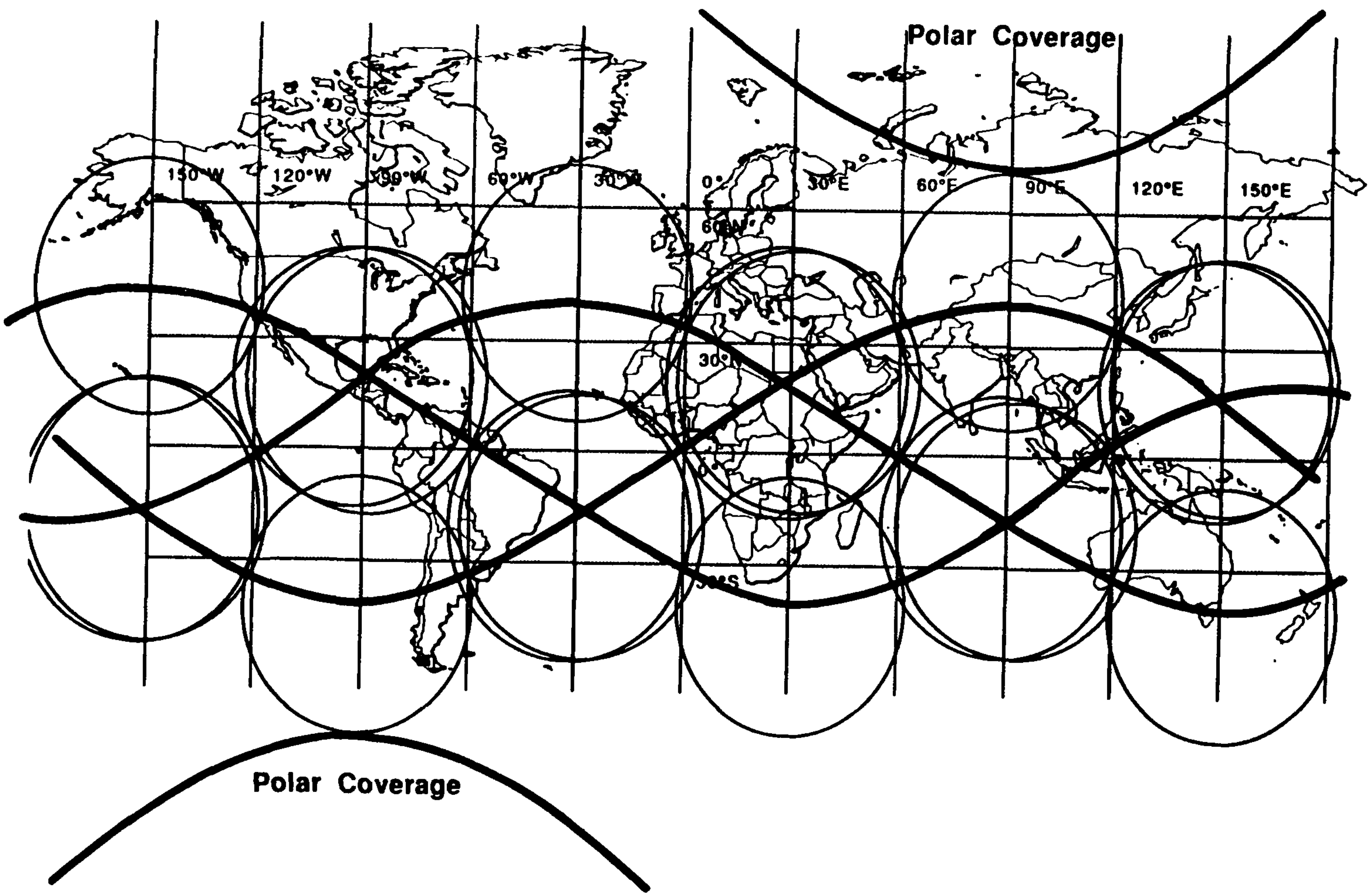

Figure 118. Twenty Satellite System Coverage

of a wide range of possible orbit inclinations and more gentle payload environments. In addition, Pegasus provide the flexibility to launch when desired without having to wait for a "piggy-back" launch on a large booster. [Ref. 78:pp. 11-12]

...Pegasus can deliver 217.5 kg (480 lb) to the desired 970 kilometer orbit at 40 degrees inclination....The Pegasus launch vehicles are expected to provide insertion accuracies of +/- 56 km in altitude and +/- 0.2 degrees in inclination. Once deployed at the nominal operational altitude, the individual orbits of the coplanar satellites will be established using each satellite's integral propulsion, or stationkeeping, subsystem. Preliminary distinct orbit altitudes will be established for each satellite. This different orbit altitude will cause the satellite to drift to its proper in-plane location relative to the other five satellites in the plane. As each satellite reaches its assigned in-plane position, the orbit altitude is changed back to the nominal one, and the stationkeeping subsystem will prevent further drift....The same procedures will be used to maintain the orthogonal and phasing relationship of the polar orbit satellites. [Ref. 78:p. 61]

Launch of the complete constellation of 20 satellites is planned to be completed within 42 months after the program is begun. Launches will be conducted at the rate of four per quarter over five quarters (fourth quarter 1993 through fourth quarter 1994). [Ref. 78:p. 91]

(3) Satellites. At the beginning of service, each satellite will weigh approximately 150 kgs (330 lbs), including five kg of fuel. The satellite will measure 7.9 meters (26 ft) in overall length from the tip of the antenna to the top of the gravity stabilizing boom [Ref. 78:p. 12]. The satellites will be three-axis body stabilized and will precisely maintain their pointing accuracy and relative position in the constellation throughout their seven-year lives [Ref 78:pp. 5-6]. Costs are estimated to be

approximately $3 million for each of the 22 satellites (20 operational plus two spares) [Ref. 78:p. 13].

The 148 MHz uplink signals from subscriber terminals and regional gateways are sent through two different paths and demodulated prior to being routed to the satellite's message processing system (MPS). Unlike simple "bent-pipe" communications satellites, the MPS performs message processing, storage, encryption and decryption; channel switching and multiplexing; and the computation of its orbital ephemeris based on GPS receiver inputs. Communications output from the MPS is modulated and routed via separate 137 MHz downlink transmitters to mobile terminals and gateways. The precision timing signals are broadcast via a 400.1 MHz transmitter.

Communication over the 20 subscriber terminal uplink channels takes place at 1200 bps with frequency-shift keying (FSK) modulation. Downlink transmissions to user terminals are phase-shift keyed (PSK) at a data rate of 4800 bps, with each of the eight channels being broadcast at a power of ten watts. Satellite to gateway communications also use PSK modulation, but at a rate of 56 kbps in both directions. Satellite transmitter power on this link is also ten watts. The 400 MHz time broadcast transmission uses PSK at 4800 kbps, but with a transmitter output of 20 watts. [Ref. 787:pp. 76-84]

d. Ground Segment

Nine regional gateways will be situated throughout the U.S. to provide coverage to any satellite within view. These gateways will be located in the following areas: Alaska, California, Florida, Hawaii, Maine, Minnesota, Puerto Rico, Texas, and Washington. The regional gateways will be connected via 56 kbps communication circuits with ORBCOMM headquarters.

The ORBCOMM headquarters will house control centers which govern the operation of the satellites, control the communications network, and perform customer service functions [Ref. 78:pp. 93-99]. A modified X.25 packet protocol will be used for communications internal to the ORBCOMM network. Large volume customers may be connected directly to the network master control center by dedicated circuits. Smaller users may be connected via public packet-switched networks. [Ref. 78:p. 53]

4. System Architecture and Operation

a. Terminals

Unlike other mobile-satellite systems, ORBCOMM does not use TDMA or slotted ALOHA techniques for mobile terminal random access. This is because of the need to preserve the very small amount of bandwidth for transmission of data packets as opposed to overhead and timing information. Instead, messages from single channel terminals are randomly transmitted onto one of 17 frequencies randomly assigned

during manufacture. Three other channels are used for polling responses. If an acknowledgement is not received within around 20 milliseconds (thousandths of a second), the unit will retransmit again. This single-channel configuration will reduce terminal costs, but subscribers may experience short communications delays during peak loading. In the case of multi-channel terminals, failure to receive an acknowledgement will cause the synthesizer to automatically scan to the next frequency before retransmitting [Ref. 78:pp. 100-101]. This will tend to equalize the communications loading on all uplink channels. Downlinked data are transmitted serially and received by all terminals within the coverage area.

Doppler positioning will function as follows:

> The ORBCOMM system will provide three levels of position determination resolution to subscribers who will require this capability. These levels are differentiated by the capability and complexity of the subscriber terminal where the calculation of position will be accomplished. Determination of position at the subscriber terminal minimizes subscriber to satellite transmissions and use of scarce spectrum.
>
> Utilizing time and position information received from the satellite in one of three frequency plans (137 MHz only, 400 MHz only, or 137 and 400 MHz in combination), the subscriber terminal will calculate its own position using the doppler frequency shift measurement technique. The shape of the curve of variance from the known carrier frequency is analyzed automatically to determine the most likely subscriber position.
>
> The subscriber terminal electronics will consist a low-cost reliable receiver operating in one of the three frequency plans plus the position determination microprocessor and memory chips. For the lowest cost, lowest performance unit, doppler shift will be derived from the satellite's 137 MHz carrier which also serves as the messaging downlink carrier. Another single channel unit

will use the 400 MHz carrier but will not have messaging capability. A number of discrete doppler measurements must be made to calculate the user position. The time for an initial position fix, using a single frequency, will be on the order of seven minutes. The 137 MHz unit is projected to have a single pass resolution to 3600 feet, or about 0.7 miles for stationary or slow moving units. The 400 MHz unit is projected to provide a resolution to 1200 feet (0.2 miles), again for stationary subscribers. Resolution for both units will improve by 30% on the second satellite pass, which will occur within 24 minutes.

For the dual carrier receiver unit, the doppler shift will be measured from a signal derived from a combination of the satellites 137 MHz and the 400 MHz carriers. Utilizing this system, the subscriber terminal is able to remove the propagation path errors caused by ionospheric refraction of the radio waves, and provide a significant improvement in the position resolution. The single pass projected resolution for this unit is 120 feet. Second and third pass resolution will improve to 85 feet and 70 feet, respectively .... [Ref. 78:pp. 110-111]

When reporting the terminal's location, the terminal controller software will poll the position determination memory for position calculations and transmit the information along with other data to the satellite. Doppler positioning is described in more detail in Appendix B.

b. Satellite

(1) Message Processing System. The satellite message processing system (MPS) operates continuously in three modes: polling, emergency response, and switching. While in view of any one of the regional gateways, the satellite will function as a "bent pipe," and continually downlink received messages. When not within range of a gateway, the MPS will act as an electronic mailbox, storing information and messages

until they are able to be downlinked to the next visible regional gateway station.

In the polling mode, the MPS receives a "polling list" from a regional gateway station. The MPS breaks down the message by terminal address and retransmits on the downlink. The polling continues until a terminal information dump or an acknowledgement is received. The return transmission is forwarded to the regional gateway within range of the satellite.

In the emergency response mode, receipt of emergency coded messages are immediately acknowledged by the MPS and forwarded to the nearest regional gateway.

In the switching mode, uplinked terminal messages are routed by the MPS to the nearest regional gateway. Uplinked messages from the regional gateway are stored in the MPS pending retransmission to the on the downlink. [Ref. 78:p. 83]

(2) Satellite Ephemeris. Each ORBCOMM satellite will carry redundant GPS receivers which will be used to fix the satellite's position within 100 meters. From thess data, the MPS will determine the satellite's position and ephemeris. A 100-bit message formatted with satellite position information and a time reference will be inserted into each of the two downlink message streams. The position, ephemeris, and time data will be cyclic on the 137 MHz downlink, but will comprise only 2% of the maximum message loading. These data

will make up the entire 400.1 MHz downlink, and will also function as a very stable reference frequency. [Ref. 78:pp. 83-84]

c. Ground Segment

Subscriber messages will flow from the satellite to a regional gateway, where they will be relayed over communication circuits to the network management control center. The message will be decoded and printed out for mailing or routed through private and public-packet switched networks. Electronic mailboxes and telephone modem services will also be offered. Emergency coded messages will be passed directly to service providers, such as auto clubs, or to ORBICOMM's customer service activity. Emergency service messages will be handled on a priority basis and will be individually managed until cleared. Messages to terminal subscribers will flow to the network control center via packet network, dial-up telephone, and hard copy. Transcription of verbal messages by a keyboard operator, similar to sending a telegram, will also be offered. The network management control center computer will provide the proper format and route the message to the appropriate regional gateway based on the subscriber's last know position. [Ref. 78:p. 106]

5. System Issues

The driving factor of the ORBCOMM system is the ability to use simple omni-directional whip antennas, mature doppler navigation technology, and conventional VHF and UHF

electronics. This minimizes research and development requirements and terminal production costs. The combined monthly service fees, usage charges, and $50 to $400 retail price of mass-produced terminals results in fully allocated user costs of below $100 per month. As discussed in Chapter V, this portion of the demand curve is elastic. ORBCOMM's user-cost structure opens up a large potential U.S. market segment which would be difficult or impossible for other geostationary systems to penetrate. For example, inexpensive emergency service mobile terminals can be installed in automobiles and share the existing broadcast AM and FM radio antenna. Subscription fees would range from $30 to $50 per <u>year</u>. The size of this potential market alone is over 120 million automobiles and vans, with 15 million new vehicles sold annually. ORBCOMM expects the emergency services segment to account for 4,500,000 terminals, or 87% of the total subscribers, after eight years of market growth [Ref. 78:pp. 56-58].

Aside from lower terminal costs, the space segment is also relatively inexpensive. Less energy is required for launch due to the lower satellite mass and orbit altitude. The satellites do not require the complex antenna systems or high power transmitters that are necessary for geostationary satellites. This enables the 20 satellites to be built and launched for around $8.6 million apiece [Ref. 78:p. 118]. The use of onboard computer programs and GPS receivers to

determine the satellite ephemeris eliminates the need for a separate ground-tracking network. Because ORBCOMM's satellites cover the earth, including the poles, the communication system could be enlarged to provide worldwide service by adding additional ground stations. Since the space segment will already be in place, the incremental expansion cost per subscriber could be low.

The ORBCOMM system is restricted to short non-voice data transmissions. The system architecture may also cause delays in data transmission and reception. While doppler position is very accurate when the receiver is stationary, the solution degrades when the receiver is in motion. Users which require voice services, long text or data messages, or highly accurate position information while moving will not be able to use this type of system. Additionally, the use of the 148-149.9 MHz band by the U.S. Government and military may pose difficulties in obtaining access to these frequencies. Alternate frequencies or a different type of modulation, such as spread spectrum, may be required if coordination is not possible. Internationally, the 148-149.9 MHz band is allocated to mobile services. Worldwide use of these frequencies will require amendment of the allocations to permit low-speed satellite mobile data services [Ref. 78:p. A-7].

6. Conclusion

If approved, this proposed system will provide the public with an entirely new and low-cost ubiquitous emergency communications service. The ORBCOMM system will likewise provide mobile satellite data services to segments of the market that are unwilling to bear the costs associated with some terrestrial or geostationary systems. The system may also capture portions of the existing terrestrial and geostationary satellite mobile data markets because ORBCOMM will be more cost, service, or coverage effective for certain applications.